CHAPTER 4. POLLUTANT SOURCE ANALYSIS

4.1 Introduction

The purpose of a TMDL pollutant source analysis is to inventory and describe all sources of pollutants that are impacting the water quality standards of the impaired waterbody. In addition, this chapter describes the processes for delivery of the pollutants and quantifies the pollutant sources within the watershed. The water quality parameters (or pollutants) considered in this Klamath River TMDL source analysis include:

- Temperature;
- Organic matter – measured as Carbonaceous Biochemical Oxygen Demand (CBOD)[1];
- Total Phosphorus;
- Total Nitrogen; and
- Dissolved Oxygen.

This analysis draws upon several sources of information and analytic tools to evaluate the various pollutant sources contributing to impairments within the Klamath River. It also draws upon the most current quality assured data available from ongoing monitoring programs conducted by various entities throughout the Klamath Basin. Application of the Klamath River TMDL models (described in Chapter 3) serves as the primary analytic tool for analyzing the water quality impacts of pollutant source loads. In addition, the source analysis incorporates information from published reports, including the approved TMDLs for the Klamath River tributaries listed below.

- Upper Klamath Lake Drainage TMDL and Water Quality Management Plan – Upper Klamath Lakes and Agency Lakes. Oregon Department of Environmental Quality – May 2002;
- Lost River, California Total Maximum Daily Loads: Nitrogen and Biochemical Oxygen Demand to address Dissolved Oxygen and pH Impairments. United States Environmental Protection Agency Region 9. December 2008;
- Staff Report for the Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads. State of California North Coast Regional Water Quality Control Board. June 2006;
- Staff Report for the Action Plan for the Scott River Watershed Sediment and Temperature Total Maximum Daily Loads. State of California North Coast Regional Water Quality Control Board. December 2005;
- Salmon River, Siskiyou County, California: Total Maximum Daily Load for Temperature and Implementation Plan. State of California North Coast Regional Water Quality Control Board. June 2005; and

[1] In this TMDL CBOD refers to CBOD- ultimate. The water quality models represent CBOD as organic matter; it is converted to CBOD-ultimate for TMDL calculations.

- Trinity River Total Maximum Daily Load for Sediment. U.S. Environmental Protection Agency Region IX. December 2001.

Pollutant loads for the year 2000 (the model calibration year) are quantified from fourteen geographic areas or entities (called 'source areas') within the Klamath River basin. Each source area has a different combination of source categories / processes at work which contribute to the load from that area. The geographic source areas can be more generally grouped as follows:

- Stateline – waters entering California from Oregon at stateline, which includes the Williamson and Sprague River watersheds, Upper Klamath Lake, the Lost River watershed that drains the Klamath Project area, municipal and industrial point sources to the Klamath River in Oregon, and Klamath River waters passing through Keno and JC Boyle Reservoirs. ODEQ's Klamath River TMDL source analysis evaluates the contributions from these discrete sources on the water quality of the Klamath River in Oregon;
- Copco 1 and 2 and Iron Gate Reservoirs – Copco 1 and 2 Reservoirs are treated as a single source for the purposes of this TMDL;
- Iron Gate Hatchery; and
- Tributaries – Five individual creeks and rivers are included as discrete source areas, while groups of smaller creeks are combined into five additional source areas for this analysis.

The Klamath River has historically been referred to as a "river of renewal." The Klamath River is unusual in that it has its origins in a naturally shallow, eutrophic lake, Upper Klamath Lake, which delivers warm water with high levels of nutrients and organic matter to the Klamath River. Due to an increasing stream gradient and inputs from tributaries with water that is both cooler and generally lower in nutrient content, the Klamath River undergoes a renewal process that leaves it in a more pristine state as the river approaches the Pacific Ocean, creating conditions that historically made it one of the most productive cold-water fisheries on the Pacific coast. Despite this unique attribute, current source loads have overwhelmed the historic renewal capabilities of the Klamath River , leading to its impaired status. The intent of the source analysis is to identify and quantify current pollutant source loads, in order to determine the source loads necessary to allow the river once again be restored through its own unique renewal capabilities.

4.1.1 Pollutant Source Categories

Both point and non-point sources of pollution contribute to the water quality impairments in the Klamath River. Land use pollutant source categories impacting Klamath River water quality are identified in Table 4.1. Though difficult to quantify exactly, and sometimes not reflected specifically by watershed models, these source categories contribute to water quality impairments in most of the Klamath River source areas. Each land use and its potential source contribution is addressed in detail in the implementation plan - Chapter 6. Chapter 6 also addresses other potential source contributions, which includes sources such as suction dredging, hard rock mining, and individual and small community wastewater collection and treatment systems in the Klamath River basin in California. Often loading from one source category contributes to multiple impairments, as shown in Table 4.1. For example, sediment delivered to the Klamath River from timber harvest related activities and roads can contribute to temperature impairments, but also may contain nutrients that can contribute to DO impairment through biostimulatory effects. Another example of a combined effect is the alteration of riparian functions, such as the degradation of vegetation that provides shade to the waterbody. Not only can this lead to an increase in the temperature load to the water column, it also increases light levels that can increase biostimulatory activity. Finally, alteration of riparian functions can reduce the capacity of the riparian zone to filter sediment and nutrients.

Table 4.1: Klamath River Anthropogenic Pollutant Source Categories Impacting Water Quality Parameters of Concern.

Land Use Source Categories Affecting	**Temperature**	**DO**	**Nutrients**	**Organic Matter**
Wetland conversion		X	X	X
Grazing	X	X	X	X
Irrigated agriculture	X	X	X	X
Timber harvest	X	X	X	X
Roads	X		X	

4.1.2 Natural Conditions Baseline - Background Loads

The starting point for the Klamath River pollutant source analysis involved quantifying natural conditions baseline water quality conditions of the river. The amount of temperature, nutrient, and organic matter loading from natural background sources varies dramatically from one geographic region to another. The TMDL source analysis and allocations recognize and account for the naturally higher background levels of nutrients and organic matter within the upper Klamath River basin in comparison to other ecoregions in California. This higher natural background loading translates into a smaller loading capacity of the river, and less available assimilative capacity to avoid excess heat load, oxygen consuming and biostimulatory conditions.

As detailed in Chapter 3, the Klamath River TMDL models were applied to characterize natural baseline water quality conditions of the Klamath River. In estimating the natural baseline water quality conditions of the Klamath River the following characteristics about the Klamath River watershed were incorporated.

The underlying geology in much of the Upper Klamath basin is of volcanic origin. Soils derived from this rock type are naturally high in phosphorus (Walker 2001). Through natural erosion and leaching processes these soils contribute a high background phosphorous load to Upper Klamath basin waters. In a nutrient loading study conducted by Rykbost and Charlton (2001), monitoring of several natural artesian springs in the upper Klamath basin were characterized by high levels of nitrogen and phosphorus, demonstrating the high natural background loading of nutrients. Upper Klamath Lake has long been noted for its eutrophic condition and demonstrated presence of high levels of organic matter (algae), including nitrogen fixing blue-green algae (Kann and Walker 2001). This nutrient and organic-matter rich Upper Klamath Lake water is the headwaters source of the Klamath River.

Within the Klamath Mountains Province of the mid- and lower-Klamath River, the underlying geology is not volcanic, and therefore does not tend to have the high levels of nitrogen and phosphorus characteristic of the Upper Klamath basin. Consequently, the tributaries that drain to the Klamath River within this province have considerably lower nutrient concentrations. As a result, the quality of the Klamath River generally improves as it flows from the Upper Klamath basin to the Pacific Ocean.

Alkalinity is a measure of the ability of water to neutralize acids. In the natural environment, alkalinity comes primarily from the dissolution of carbonate rocks. Carbonate rock sources are rare in much of the Klamath basin due to its volcanic origin. As a result, the Klamath River has a relatively low alkalinity (<100 mg/L). The low alkalinity provides for a weak buffering capacity of Klamath River water. Photosynthetic activity removes carbon dioxide in the water (in the form of carbonic acid) which increases the water pH. Natural alkalinity serves as a buffer to minimize the photosynthetically induced increase in pH. In low alkalinity waters such as the Klamath River, this buffering capacity is frequently exceeded and high pH values are observed during daytime hours when photosynthesis is occurring. The large daily variation of pH observed in the Klamath River is caused by photosynthetic activity in the low alkalinity water.

Further exacerbating the effect of the naturally productive and weakly buffered system is the presence of regionally high ambient summer air temperatures, and the resulting high heat load to the shallow and predominantly un-shaded Upper Klamath Lake. These naturally warm waters are the source of the Klamath River. In addition, the east-west aspect of much of the Klamath River also makes it prone to heating, even within the steep gorges of some reaches of the river.

In summary, the high ambient air temperatures, coupled with the high levels of biological productivity and respiration that is enhanced by the high levels of biostimulatory nutrients, yield large volumes of organic matter, seasonally high water temperatures, daily low dissolved oxygen, and high pH levels. All of these water quality conditions can be extremely stressful to many forms of aquatic life. These natural background heat, nutrient, and organic matter loads to the Klamath River underscore the very limited capacity of the river to assimilate anthropogenic pollutant sources, and the necessity for establishing load allocations that will result in attainment of water quality standards.

4.1.3 Pollutant Source Loads - Overview
The Klamath TMDL models were used to calculate loads for the year 2000, and for purposes of the Klamath TMDL, year 2000 loads represent current loading conditions.

The cumulative pollutant loads to the Klamath River for the year 2000 are identified in the schematic diagrams below (Figures 4.1, 4.2, and 4.3). These figures provide an illustration or graphical representation of the current cumulative loading to the Klamath River for total phosphorus, total nitrogen, and organic matter (CBOD[2]) from the fourteen source areas within California. Cumulative loads used in this analysis include the total annual mass generated from upstream sources that pass through the assessment location. The analysis represents a mass-balance of loads in California that sums all of the mass inputs and outputs to reaches of the river on an annual basis and, includes within-stream and reservoir dynamics (e.g., losses, retention, and fluxes). The width of a segment arrow is proportional to the magnitude of the loading for that reach. These figures demonstrate that, unlike in many other river systems, the Klamath River pollutant loads are larger (~50% of the total load) in the upper half of the basin. The source area loads are also summarized in Table 4.2. Figures 4.1, 4.2, and 4.3 and Table 4.2 provide a comprehensive overview of current loading conditions. Table 4.2 also presents natural conditions baseline loadings for comparison. In addition, Table 4.2 provides source loading estimates for the critical six month period (May – October) when water quality impairments are worse. Finally, Table 4.2 presents the percentage of annual loading associated with each parameter for each source area.

Given the different units typically used to characterize heat load, vector diagrams and a summary table are not presented to summarize the temperature loads to the Klamath River. The temperature effects from different source areas and source categories are presented in Section 4.2.

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[2] CBOD is a quantitative measure of the amount of dissolved oxygen required for the biological oxidation of carbon-containing compounds.

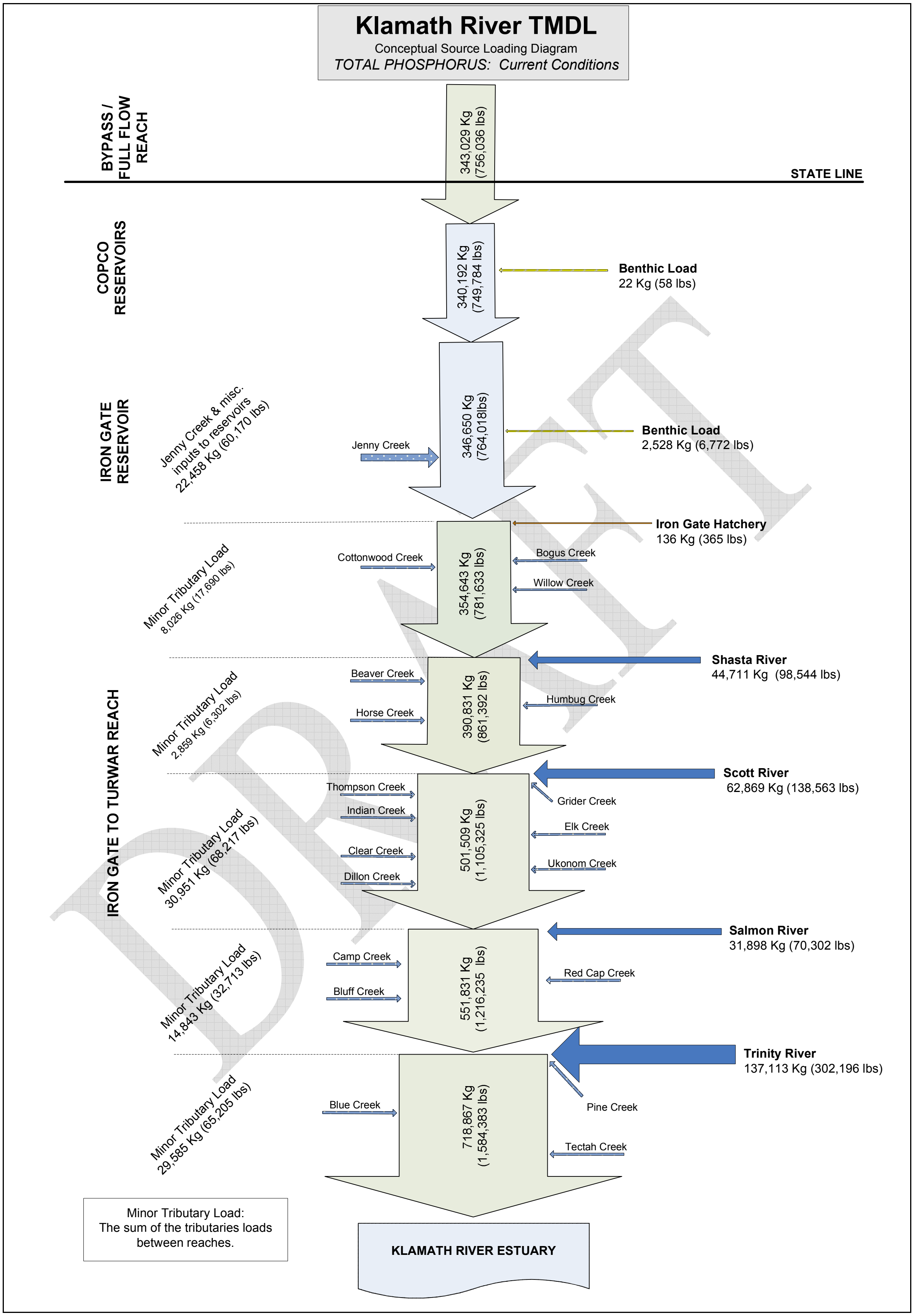

Figure 4.1: Current total phosphorous annual loading diagram

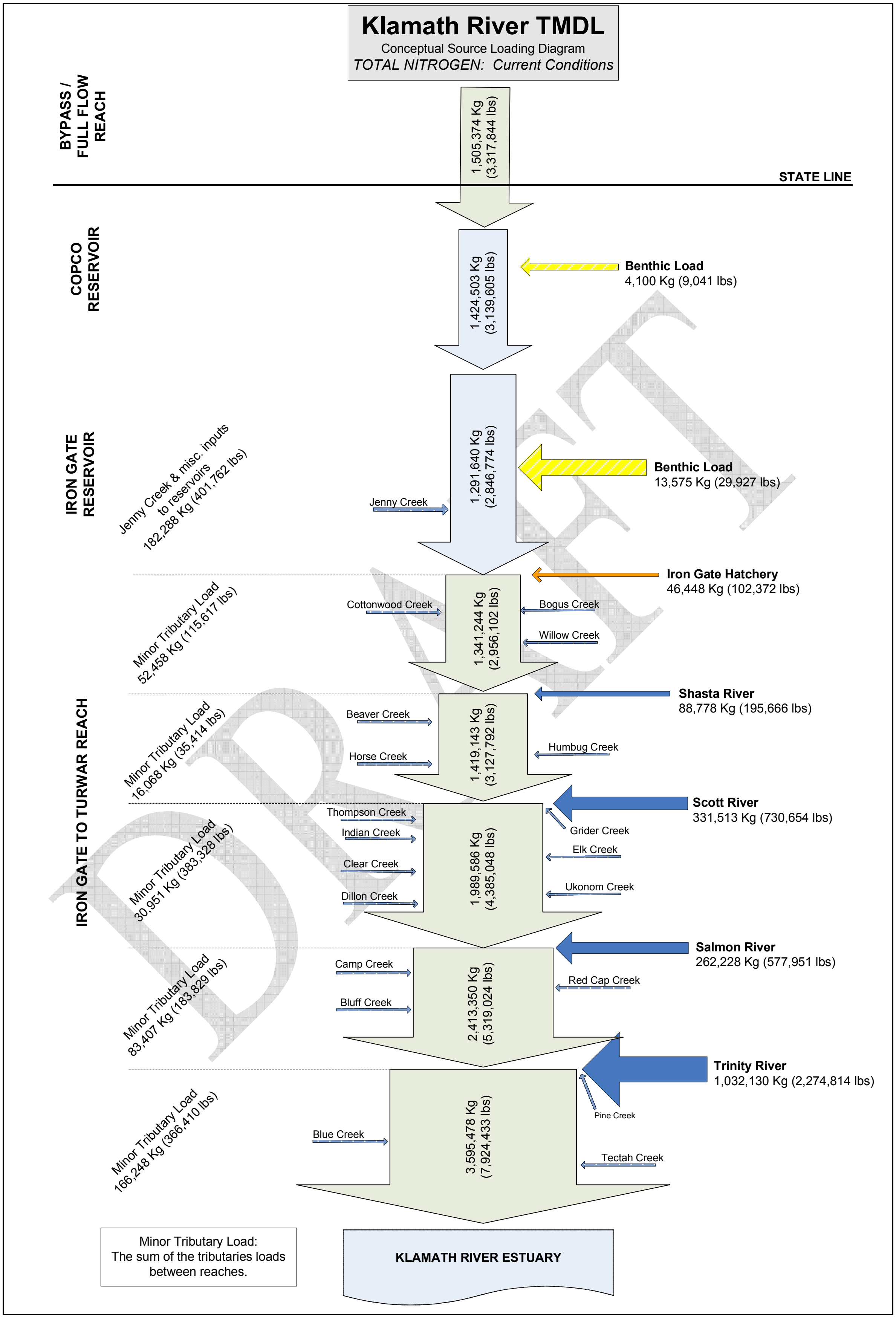

Figure 4.2: Current total nitrogen annual loading diagram

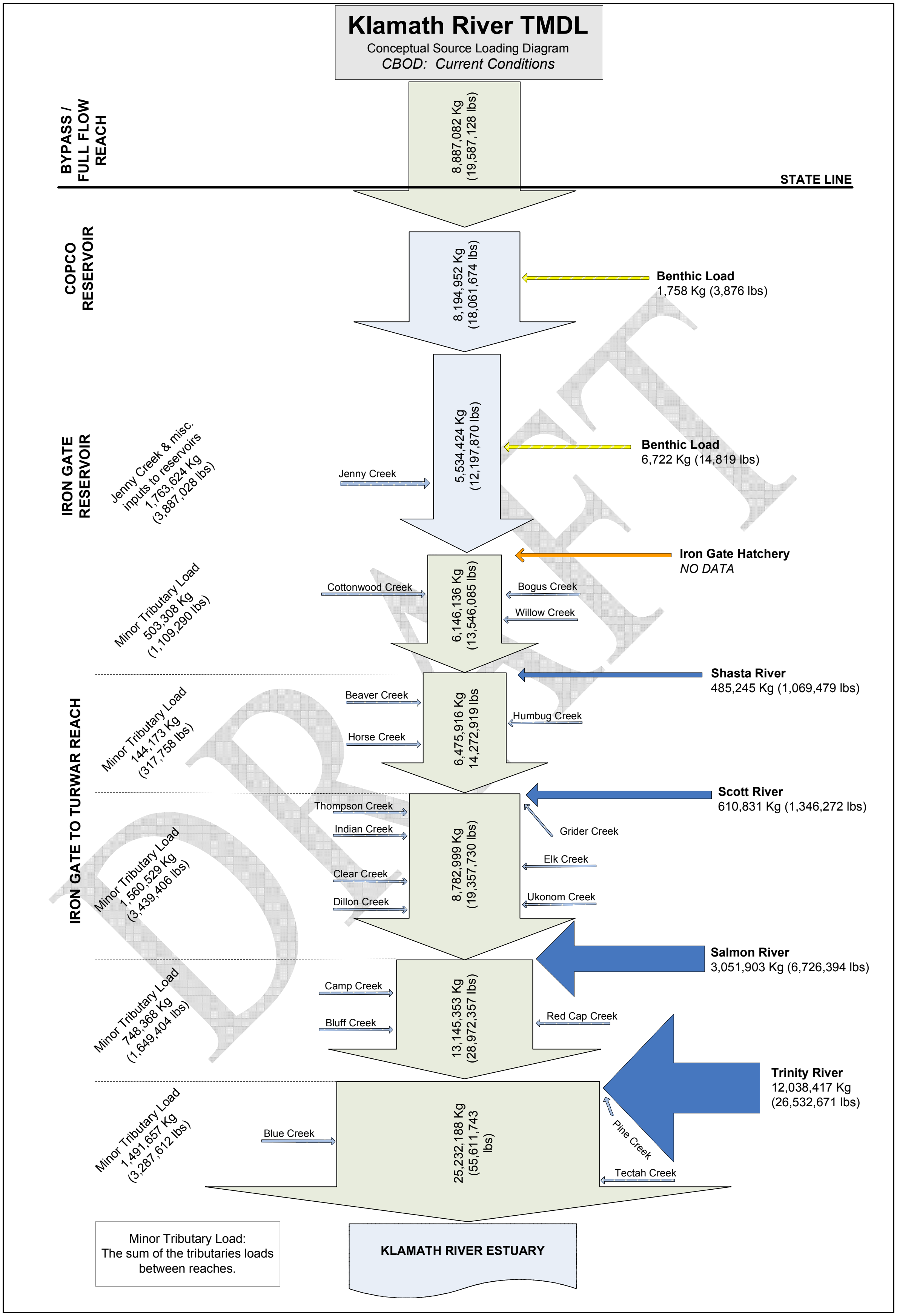

Figure 4.3: Current organic matter (as CBOD) annual loading diagram

Table 4.2: Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California

Klamath River TMDL Source Analysis Summary										
		Annual Source Loads (lbs.)			Critical Period Source Loads (lbs.) May - October (six months)			Current Percent Total Annual Loading		
Source Area		TP	TN	CBOD	TP	TN	CBOD	TP	TN	CBOD
Klamath River - Stateline	Current	756,036	3,317,844	19,587,128	336,092	1,384,030	6,057,025	46.6%	38.5%	28.4%
	Natural Baseline	125,129	1,371,919	11,536,548	51,719	542,311	4,124,493			
Copco Reservoir Outlet	Current	749,784	3,139,605	18,061,674	337,863	1,187,850	5,114,281			
	Natural Baseline	125,134	1,371,911	11,416,187	50,990	534,171	4,085,650			
Copco Reservoirs – sediment flux	Current	58	9,041	3,876	44	8,286	2,478	0.0%	0.1%	0.0%
	Natural Baseline	0	0	0	0	0	0			
Stateline to Iron Gate inputs	Current	60,170	401,762	3,887,028	15,192	101,436	981,390	3.7%	4.7%	5.6%
	Natural Baseline	60,170	401,762	3,887,028	15,192	101,436	981,390			
Iron Gate Reservoir Outlet	Current	764,018	2,846,774	12,197,870	340,710	921,302	3,390,355			
	Natural Baseline	137,675	1,507,003	12,347,969	56,855	595,266	4,531,091			
Iron Gate Reservoir – sediment flux	Current	6,772	29,927	14,819	3,770	15,640	13,322	0.4%	0.3%	0.0%
	Natural Baseline	0	0	0	0	0	0			
Iron Gate Fish Hatchery	Current	365	1,361	no data	182	680	no data	0.0%	0.0%	no data
	Natural Baseline	0	0	0	0	0	0			
Iron Gate to Shasta Tributaries ▪ Bogus Creek ▪ Willow Creek ▪ Cottonwood Creek	Current	17,690	115,617	1,109,290	4,697	30,701	294,558	1.1%	1.3%	1.6%
	Natural Baseline	17,690	115,617	1,109,290	4,697	30,701	294,558			
Shasta River	Current	98,544	195,666	1,069,479	33,104	64,093	592,149	6.1%	2.3%	0.9%
	Natural Baseline	27,284	80,259	878,229	8,916	26,298	288,023			

Table 4.2 (cont.): Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California

Klamath River TMDL Source Analysis Summary										
		Annual Source Loads (lbs.)			Critical Period Source Loads (lbs.) May - October (six months)			Current Percent Total Annual Loading		
Source Area		**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**
Shasta to Scott Tributaries ▪ Humbug Creek ▪ Beaver Creek ▪ Horse Creek	Current	6,302	35,414	317,758	1,673	9,401	84,348	0.4%	0.4%	0.5%
	Natural Baseline	6,302	35,414	317,758	1,673	9,401	84,348			
Scott River	Current	138,563	730,654	1,346,272	52,957	208,948	1,056,452	8.5%	8.5%	2.0%
	Natural Baseline	138,563	730,654	1,346,272	52,957	208,948	1,056,452			
Scott to Salmon Tributaries ▪ Grider Creek ▪ Thompson Creek ▪ Happy Camp Creek / Indian ▪ Elk Creek ▪ Clear Creek ▪ Ukonom Creek ▪ Dillon Creek	Current	68,217	383,328	3,439,406	12,978	72,930	654,360	4.2%	4.4%	5.0%
	Natural Baseline	68,217	383,328	3,439,406	12,978	72,930	654,360			
Salmon River	Current	70,302	577,951	6,726,394	15,358	192,412	1,946,043	4.3%	6.7%	9.8%
	Natural Baseline	70,302	577,951	6,726,394	15,358	192,412	1,946,043			
Salmon to Trinity Tributaries ▪ Camp Creek ▪ Red Cap Creek ▪ Bluff Creek	Current	32,713	183,829	1,649,404	6,002	33,726	302,610	2.0%	2.1%	2.4%
	Natural Baseline	32,713	183,829	1,649,404	6,002	33,726	302,610			
Trinity River	Current	302,196	2,274,814	26,532,671	56,891	460,714	4,780,372	18.6%	26.4%	38.5%
	Natural Baseline	302,196	2,274,814	26,532,671	56,891	460,714	4,780,372			
Trinity River to Turwar Tributaries ▪ Pine Creek ▪ Tectah Creek ▪ Blue Creek	Current	65,205	366,410	3,287,612	11,972	67,277	603,640	4.0%	4.2%	4.8%
	Natural Baseline	65,205	366,410	3,287,612	11,972	67,277	603,640			

4.2 Pollutant Source Area Loads

This section discusses the pollutant loads from the key source areas.

4.2.1 Stateline – Upper Klamath Basin

4.2.1.1 Temperature

The combined water temperature effects of sources of increased thermal loads in Oregon were evaluated by comparing the results of the current condition model scenario with the natural condition scenario at the California-Oregon border. The results, summarized in Figure 4.4, indicate that the sum of all sources upstream of California lead to significant temperature increases, possibly as much as 9 ^{o}F (5 ^{o}C), from approximately April to December. The combined sources include alterations due to discharge of irrigation return flows (Klamath Straits Drain, Lost River Diversion Channel) and changes in hydrodynamics resulting from reservoir operations (Keno, JC Boyle).

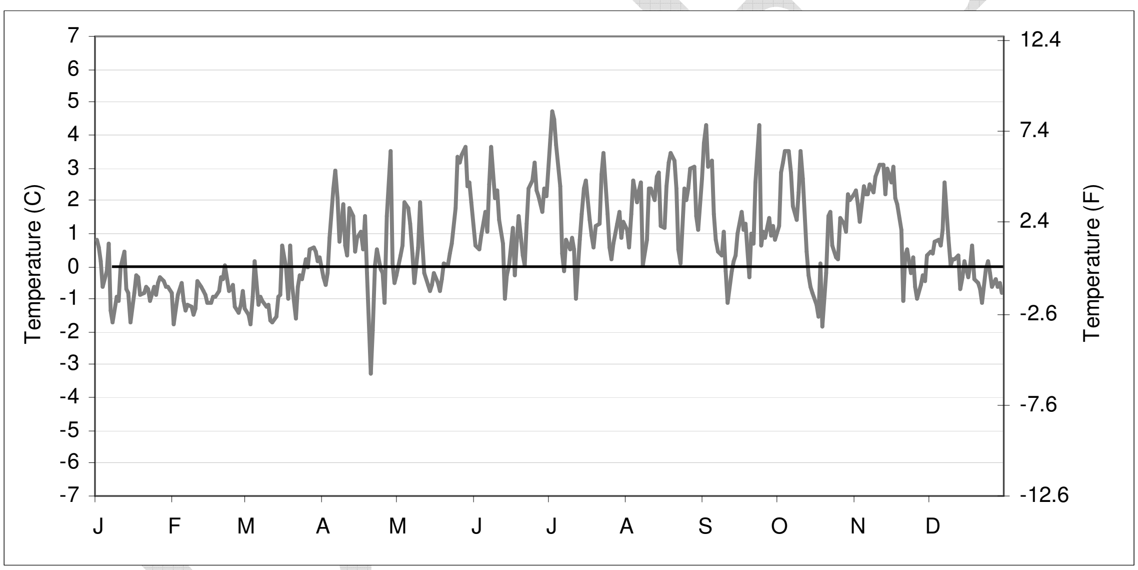

Figure 4.4: Estimated temperature changes at Stateline due to reservoirs and irrigation return flows upstream. Positive values represent an increase above the natural conditions baseline.

The diversion of water directly from the Klamath River and its tributaries, including Upper Klamath Lake, greatly alters the flow of the Klamath River, primarily in the spring. Reductions in flow can lead to increased diurnal temperature fluctuations, as well as increased daily average temperatures. These concepts are detailed in Section 2.4.3.3.

As described in Section 3.3.2, the natural conditions baseline scenario was developed using current flows from Upper Klamath Lake and the Klamath Project area, and therefore does not reflect thermal impacts caused by irrigation diversions. Thus, Figure 4.4 also does not reflect those thermal effects. Figure 4.5 presents the difference in daily maximum temperature predicted to occur at the stateline solely from the diversion of water (i.e. no dam effects and no irrigation return flows). The temperature difference between the two scenarios is generally slight, but may account for as much as 2.7 ^{o}F (1.5 ^{o}C) increase in daily maximum temperature in early spring. The relatively minimal difference in stream temperatures at stateline is likely due to the fact that the source of the Klamath River, Upper Klamath Lake, is a relatively warm waterbody, reaching equilibrium temperatures irrespective of alteration in flow conditions.

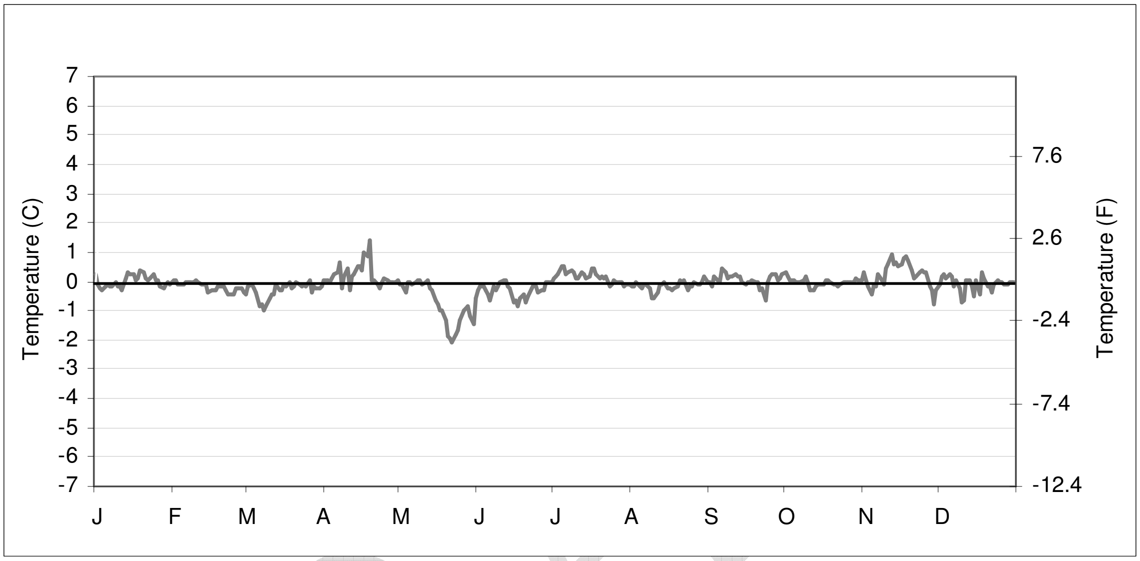

Figure 4.5: Estimated change in daily maximum temperature at Stateline resulting from altered flows, 2000 simulation year. Positive values represent an increase in temperatures due to reduced flow.

4.2.1.2 Nutrients and Organic Matter

The greatest nutrient and organic matter loads to the Klamath River originate in the Upper Klamath basin above stateline. Current TP and TN loads at Stateline comprise over 50% of the total nutrient loading to the Klamath River (Table 4.2). The fraction for CBOD is somewhat less at 28%. Figure 4.6 compares the current annual TP, TN, and CBOD loads at Stateline to those estimated loads under natural conditions baseline, reflecting 504%, 142%, and 70% increases in annual loads from natural conditions baseline for TP, TN, and CBOD, respectively.

All of the land use source categories identified in Section 4.1.1 contribute to the increased loads at Stateline. The Upper Klamath Lake Drainage TMDL (ODEQ 2002) analyzes the sources contributing loads to Upper Klamath Lake. In addition to irrigated agriculture, upland sources (e.g., gravel road surface erosion, timber harvest operations), nutrient flux from reclaimed wetlands, and internal nutrient loading from Upper Klamath Lake bottom sediments contribute to loading to Upper Klamath Lake. Irrigated agricultural practices within the Klamath Project area contribute loading to the Klamath River at Klamath Straights Drain and intermittently at the Lost River Diversion Channel. Those sources within the California portion of the Lost River are analyzed in the Lost River, California

TMDL (USEPA 2008). Finally, municipal and industrial point sources discharge to the Klamath River within Oregon. There are two municipal wastewater point sources that discharge to the Klamath River in Oregon: South Suburban Sanitation District and Spring Street Sanitation plant run by the City of Klamath Falls. There are two industrial wastewater point sources that discharge to the Klamath River in Oregon: Columbia Forest Products, and Collins Forest Products.

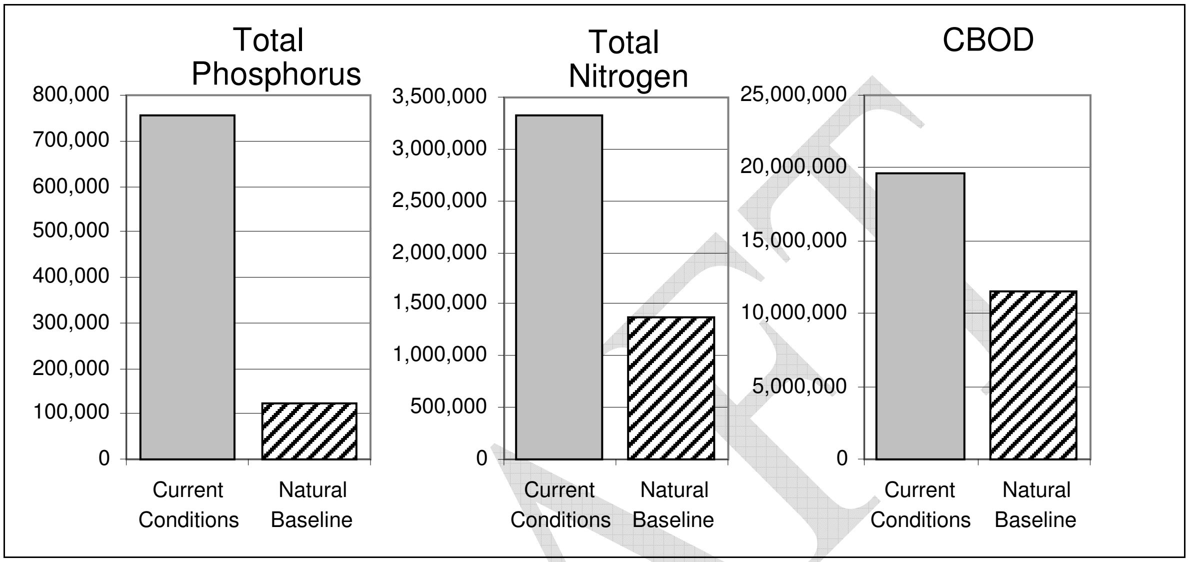

Figure 4.6: Comparison of Current Annual TP, TN, and CBOD Loads at Stateline to Natural Conditions Baseline Loads.

4.2.2 Copco 1 and 2 and Iron Gate Reservoirs

4.2.2.1 Temperature

An analysis of model results was prepared that isolates the effects of each reservoir (Copco 1 and 2 and Iron Gate), in order to evaluate the impacts of the reservoirs on Klamath River temperature. The effects of the reservoirs were isolated by calculating the change in river temperature between the upstream and downstream limits of each reservoir for both current and natural conditions baseline. The temperature impact of each reservoir was calculated by subtracting the change in temperature that would result from free-flowing conditions (i.e. in the absence of the reservoirs) in the reservoir reaches from the change in temperature that currently occurs in the reservoir reaches. The resulting calculation estimates the change in temperature due to the presence of the reservoirs, by subtracting the amount of heating expected to occur in a natural (free-flowing) state.

The results of the modeling analysis demonstrate that the presence of Copco 1 and 2 significantly influences the temperature of the Klamath River. Figure 4.7 presents the change in daily maximum temperature associated with the presence of the reservoir for the 2000 calendar year. These results indicate that the presence of Copco Reservoir increases Klamath River water temperatures by more than 5.4 ^{o}F (3.0 ^{o}C) during the late summer and fall months.

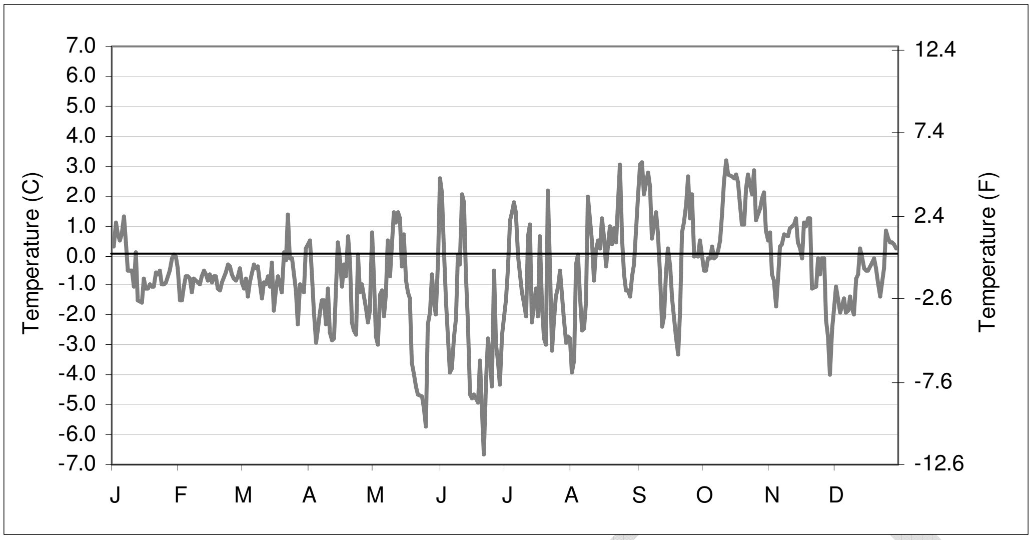

Figure 4.7: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Copco Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Copco 1 and 2.

The results of the Iron Gate modeling analysis are very similar to the Copco analysis results. The results also demonstrate that the presence of Iron Gate Reservoir significantly influences the temperature of the Klamath River. Figure 4.8 presents the change in daily maximum temperature associated with the presence of the reservoir for the 2000 calendar year. These results indicate that the presence of Iron Gate Reservoir increases Klamath River water temperatures by up to 6.3 ^{o}F (3.5 ^{o}C) during the fall months. The timing of this increase coincides with the time when Chinook salmon currently spawn in the Klamath River mainstem directly downstream of the reservoir.

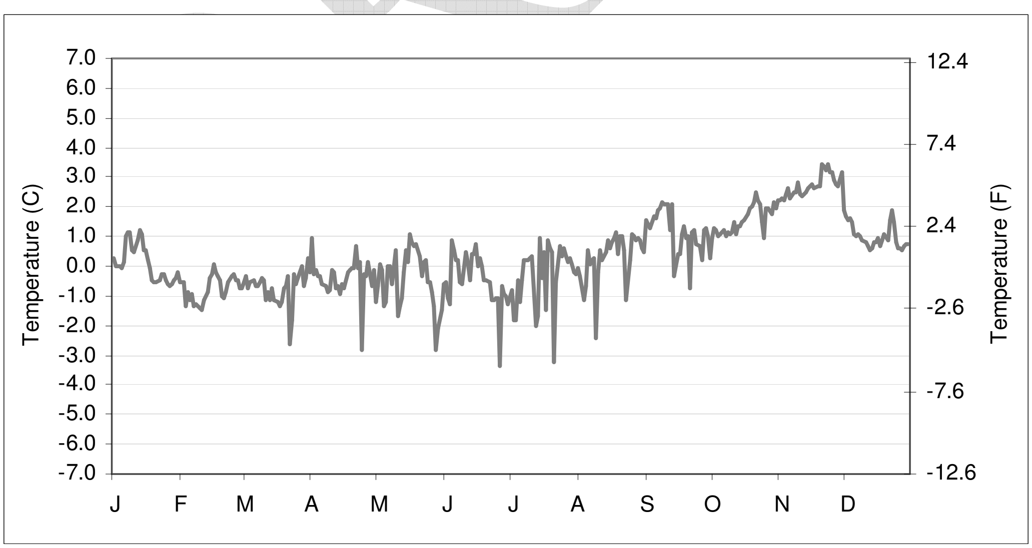

Figure 4.8: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Iron Gate Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Iron Gate Reservoir.

The analyses of Iron Gate and Copco Reservoirs indicate that each of these reservoirs can increase Klamath River temperatures by as much as 6.3 ^oF (3.5 ^oC). However, in reality the effects of the reservoirs are not additive and do not necessarily result in a total increase of up to 12.6 ^oF (7.0 ^oC). This is because Copco Reservoir heats the water to a level close to the equilibrium temperature, so the water is close to equilibrium when entering Iron Gate Reservoir. The rate of heating is proportional to the difference between the instantaneous temperature and the equilibrium temperature. This concept is taken into account and addressed in the load allocation and implementation recommendations for these facilities.

4.2.2.2 Nutrients, Organic Matter, and Dissolved Oxygen

The presence of Copco 1 and 2 and Iron Gate Reservoirs creates DO conditions that do not meet water quality standards. Iron Gate and Copco Reservoirs become stratified during the summer months with warm, dissolved oxygen-rich water near the surface and colder, dissolved oxygen-poor water near the bottom. There is no overlapping layer that has DO and temperature conditions that are both supportive of COLD for much of the summer season. In Iron Gate Reservoir, the levels of dissolved oxygen are only suitable for rainbow trout to a depth of 4 meters, on average (rainbow trout are assumed to be the most sensitive cold water-dependent species currently present). However, temperatures in Iron Gate Reservoir are not low enough to fully support rainbow trout above a depth of approximately 10 meters. Copco Reservoir similarly stratifies, with suitable dissolved oxygen above approximately 7.5 meters depth and suitable temperatures below 17 meters deep. By contrast, under free-flowing river and natural temperature conditions, there would be co-occurring temperature and DO conditions that meet standards.

The occurrence of DO conditions that do not meet standards within Copco 1 and 2 and Iron Gate Reservoirs during summer months is due to the physical characteristics of reservoirs and the nutrient and organic matter loads entering the reservoirs, but is exacerbated by internal nutrient and organic matter loading within the reservoirs.

Internal Nutrient Loading Within Reservoirs

Reservoirs alter the nutrient dynamics of a river system. By design, reservoirs represent areas of a river system in which velocity is decreased and residence time increased. This encourages the settling of particulate material, including both nutrient-bearing organic material and algae, and nutrients (i.e. PO_4 and NH_4) sorbed to inorganic sediment. In addition, the physical characteristics of reservoirs cause them to stratify during summer months, resulting in the bottom layer of the reservoir (i.e. hypolimnion) becoming devoid of oxygen (i.e. anoxic). Under these conditions organic debris (including dead algal detritus) that has settled to the bottom of the reservoir is subject to one or more of the following processes that can lead to the transfer of nutrients from the reservoir bottom sediments back into the water column, also known as internal nutrient loading:

- If the sediments are disturbed by wind-driven currents or by other means (organisms or degassing) interstitial nutrients can be transferred to the water column simply by agitation.

- Decrease in the redox potential (increase in the availability of electrons) in the surficial bottom sediments caused by intensive microbial respiration, as would be the case for highly organic sediment, can cause biogeochemical changes that result in accelerated release of mineralized or soluble organic phosphorus and ammonia from the sediments to the overlying water, even if the sediments are immobile.
- High pH at the sediment surface may cause release of adsorbed phosphorus from sediments, with or without agitation of sediments.
- In shallow lakes, suspended algae cells may, under calm conditions, sink to deeper waters at or below the thermocline, where phosphorus is more concentrated than in the surface waters where most photosynthesis occurs, and then be re-suspended either by wind or buoyancy control mechanisms after assimilating phosphorus, thus bringing phosphorus from the sediments to the water column.

These internal nutrient loading processes can occur simultaneously within a reservoir, and serve as an input (or source) of nutrients into the water column or the reservoir. In turn, phosphate (PO_4) and ammonia (NH_4), the dissolved inorganic nutrients that were once sequestered within the sediments, become available for uptake by planktonic algae within the reservoir, or can move out of the reservoir and be available for uptake by attached algae (i.e. periphyton) in downstream river reaches. This export of dissolved inorganic nutrients from the reservoir to the river can occur within the window of the critical growth period for periphyton within the river.

<u>Nutrient Retention Within Free-Flowing Rivers</u>
In support of Klamath River TMDL development, Tetra Tech assessed the nutrient dynamics of the Klamath River (see Appendix 1, TetraTech 2008). This assessment evaluated the nutrient retention capacity of the Klamath River reservoirs in California, as well as the potential nutrient retention capacity of the river under free-flowing conditions. This assessment is included as Appendix 1 of this report.

As described in Appendix 1 (TetraTech 2008), physical and biological processes in free-flowing river reaches can result in both net removal and temporary retention of nutrients. One of the major processes for temporary retention is uptake of nutrients by periphyton. Periphytic algae, as well as heterotrophic organisms, require nutrients for growth and remove inorganic nutrients from the water column, converting them to organic biomass. Heterotrophs also remove organic matter as foodstock. This storage, however, is temporary. In addition to normal dieoff and predation, periphyton is subject to scour and transport downstream during high flow events.

Temporary retention in river reaches also occurs as a result of settling and storage of particulate matter, including organic detritus. Inorganic orthophosphate and, to a lesser extent, ammonium can also sorb to sediment particles and settle out. These processes also largely constitute temporary retention, as the stored particulate matter can be remobilized by scouring flows.

Permanent removal of nutrient mass can also occur in several ways. For nitrogen, denitrification and conversion to nitrogen gas results in a permanent loss of nitrogen from the water to the air. This may be balanced by fixation of atmospheric nitrogen by certain types of cyanophytes, but these are usually not dominant in flowing waters. Water lost to deep groundwater, agricultural diversions, or riparian wells can remove nutrients, and is more important for nitrogen, which is more soluble than phosphorus. Effective removal of phosphorus may also occur due to burial in deposits that are not readily remobilized (due, for instance, to stream meander and cutoffs), export to the floodplain, or conversion to tightly bound, insoluble mineral forms. These latter processes tend to be of less importance in higher gradient systems, such as the Klamath, so net rates of removal for TP are expected to be less than net rates of removal for TN in the Klamath.

TMDL Model Results

Figures 4.9 and 4.10 present a comparison of current and natural conditions baseline cumulative loads of TP, TN, and CBOD at the outlet of Copco 1 and 2 and Iron Gate Reservoirs. Cumulative loads used in this analysis include the total annual amount of mass generated from upstream sources that pass through the assessment location. The analysis is a model generated mass-balance calculation that sums all of the mass inputs and outputs to the assessment location on an annual basis including within stream and reservoir dynamics (e.g., losses, retention, and fluxes). Locations of the loading estimates for the natural conditions baseline scenario are consistent with the location on the river at the outlet of Copco 2 and Iron Gate. In addition to representing a free-flowing river (i.e. no impoundments present), the natural conditions baseline scenario represents natural water quality conditions. Therefore the differences in loadings are due to the difference in water quality conditions entering the river reaches occupied by the reservoirs, not simply by the presence of Copco 1 and 2 and Iron Gate under current conditions. Nonetheless, the figures illustrate the large increase in current nutrient loads, particularly total phosphorus, at these locations compared to natural conditions baseline.

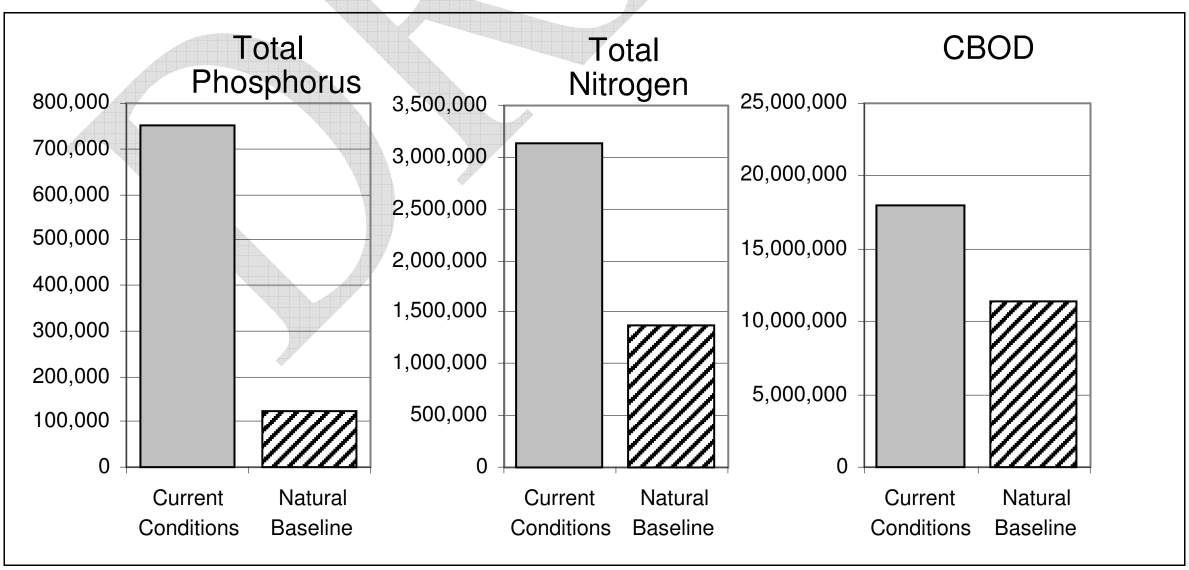

Figure 4.9: Comparison of Current Annual Loads of TP, TN, and CBOD with Natural Baseline Loads at Copco Reservoirs

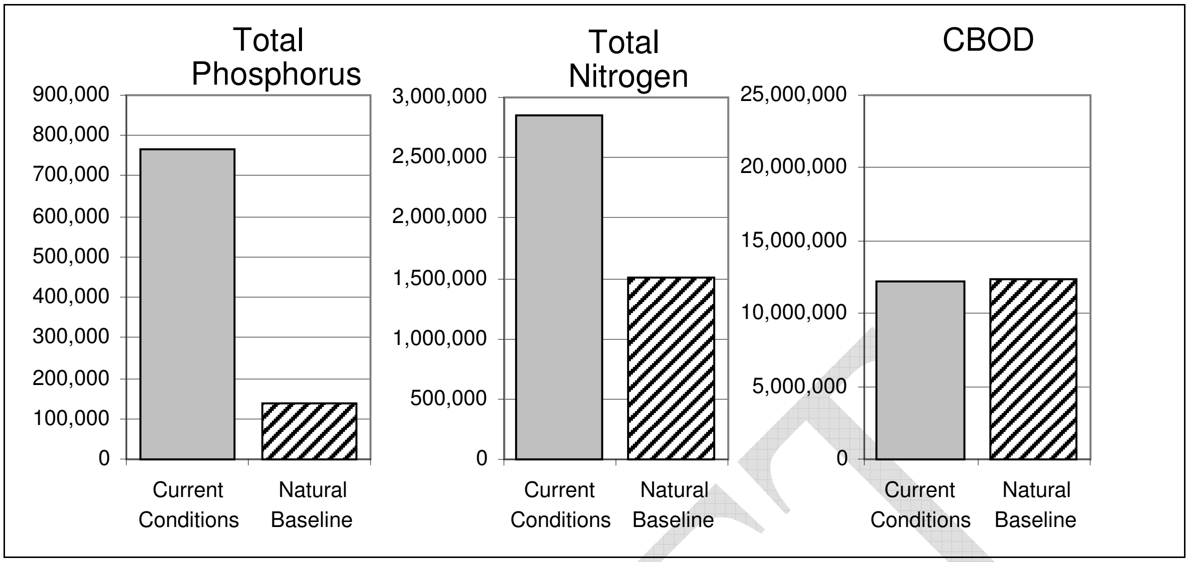

Figure 4.10: Comparison of Current Annual Loads of TP, TN, and CBOD with Natural Baseline Loads at Iron Gate Reservoir

The differences in CBOD load are smaller. In fact, the CBOD loading estimates indicate a slightly higher load at the location of the outlet of Iron Gate under natural conditions baseline. The estimated lower annual mass of CBOD at Iron Gate under current conditions is explained by the settling and trapping function of the reservoirs along with longer residence time with the dam in place that allows for greater decay of influent CBOD. In the pre-dam era organic matter such as decaying algal tissue generated in Upper Klamath Lake and other organic debris captured in storm runoff would largely be swept downstream and deposited in low gradient reaches or be washed out through to the estuary. With the placement of dams along the river the impoundments create low velocity conditions which allow for much of this organic material to settle out into the reservoir sediments. However a simple comparison of organic mass totals (as CBOD) does not tell the whole story. The reservoir impoundments create an environment favorable to increased suspended algae productivity. The increased algal growth offsets some of the organic matter loss through settling by fixing carbon from the atmosphere through growth and exporting this organic matter downstream through the reservoir outlets. The effect of this change in form and timing of organic matter loading is not completely understood but is addressed briefly in the Klamath nutrient conceptual model discussion in Section 2.4.2.1.

Table 4.3 presents the current TP, TN, and CBOD loadings at Stateline, Copco 2 outlet, and Iron Gate outlet based on model results, and identifies the change in loading for these parameters between Stateline to Copco and between Stateline and Iron Gate. Within the critical summer growth period (May – October), there is currently an approximate increase in TP loads of 1% from Stateline to Copco Reservoir, and from Stateline through Iron Gate Reservoir. These model results indicate that under current conditions the reservoirs increase TP loads delivered to the river. On the other hand, TN and CBOD annual loads are currently decreased by 14% and 38%, respectively, within the river reach that occupies the reservoirs.

Table 4.3 Current Total Phosphorus, Total Nitrogen, and CBOD Loads at Stateline, Copco Outlet, and Iron Gate Outlet, and Associated Loading Changes

Current Conditions	Annual Source Loads (lbs.)			Critical Period Source Loads (lbs.) May - October (six months)		
Source Area	**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**
Klamath River - Stateline	756,036	3,317,844	19,587,128	336,092	1,384,030	6,057,025
Copco Reservoirs – tailrace	749,784	3,139,605	18,061,674	337,863	1,187,850	5,114,281
Iron Gate Reservoir – tailrace	764,018	2,846,774	12,197,870	340,710	921,302	3,390,355
Loading Change	**Annual Source Loads**			**Critical Period Source Loads May - October (six months)**		
Stateline to Copco Reservoir	-1%	-5%	-8%	1%	-14%	-16%
Stateline to Iron Gate Reservoir	1%	-14%	-38%	1%	-33%	-44%

In order to isolate the change in nutrient loads from Copco 1 and 2 and Iron Gate attributed to the release of nutrients from the bottom sediments under anoxic conditions, a sensitivity analysis was run using the Klamath TMDL model. The model includes a benthic flux term that simulates the release of nutrients from sediments at the bottom of the reservoir under anoxic conditions. When the benthic flux term is turned *off* for both reservoirs within the model, no nutrients are released from the bottom sediments, even when anoxic conditions in the hypolimnion are simulated in the model. A comparison of resulting nutrient concentrations at the outlet of Iron Gate under two scenarios (with the benthic flux term turned on or off for both reservoirs) indicates the relative contribution to nutrient concentration (and load) resulting from the release of nutrients from bottom sediments under stratified anoxic conditions.

The results of this comparison at Iron Gate Dam for inorganic phosphate (PO_4) are illustrated in Figure 4.11, and demonstrate an increase in downstream PO_4 concentrations beginning in early June (beginning of summer stratification) and tapering off in late November (post turnover – no stratification). Any peak above the mid-line (0.000) suggests higher concentrations of PO_4 being released during stratified anoxic conditions from sediments at the bottom of the reservoirs downstream through the reservoir outlet. This increase occurs during the critical growth period for downstream periphyton, contributing to biostimulatory conditions.

Results of this benthic flux sensitivity analysis are also used to quantify the annual nutrient loading to Copco 1 and 2 and Iron Gate attributed to nutrient release from bottom sediments. The total annual TP and TN loads from Copco 1 and 2 bottom sediments is 1,940 pounds and 9,041 pounds, respectively. The total annual TP and TN loads from

Iron Gate bottom sediments is 6,772 pounds and 29,927 pounds, respectively. While these loadings are small compared to the current loadings entering the reservoirs, they do represent an increase in nutrient loading that would not occur in the absence of anoxic conditions, created by the presence of the reservoirs.

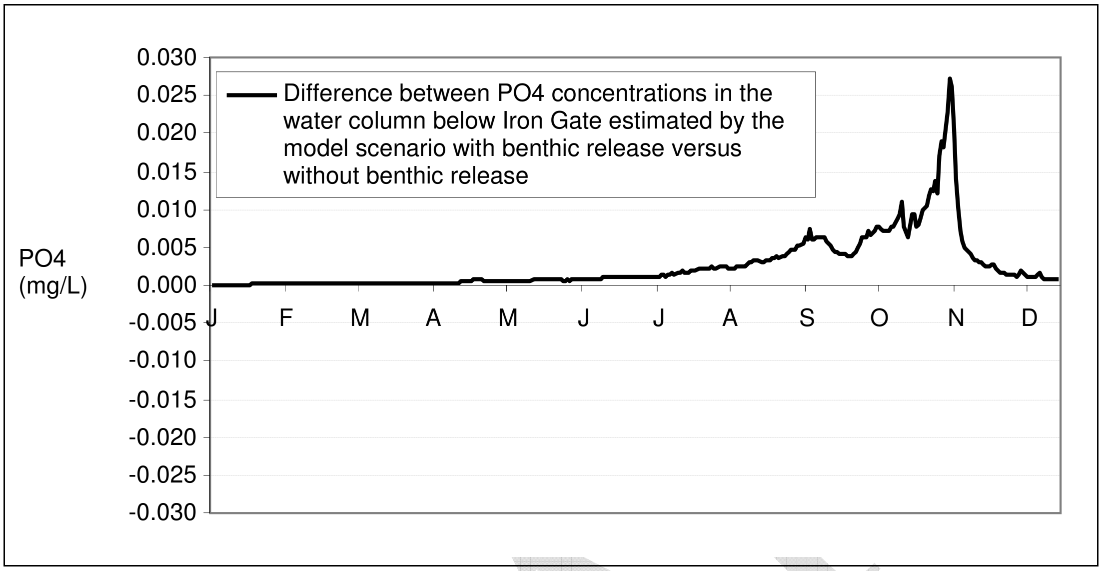

Figure 4.11: Comparison of PO_4 concentrations immediately downstream of Iron Gate Reservoir illustrating contribution of nutrient flux from reservoir sediments under anoxic conditions (summer stratification).

Annual and critical summer season bottom sediment TP and TN loads for both Copco and Iron Gate are presented in Table 4.2. A comparison of the current annual and critical season loads for Copco 1 and 2 and Iron Gate Reservoir bottom sediments demonstrates that the majority of these loads occur during the summer months. The summer months are the critical growing season, the period when an increase in biostimulatory conditions exacerbates the water quality impairments in the Klamath. Therefore, both the timing and form of this source load contribution contributes to the water quality impairments.

Available monitoring data for the stream reach immediately downstream of Iron Gate Dam demonstrates distinct seasonal differences in nutrient concentrations. Total phosphorus, ortho-phosphate, total nitrogen, and total inorganic nitrogen concentration data collected between 1990 to 2007 from below Iron Gate Dam to river mile 176 were compiled and grouped by season: March to June (pre-reservoir stratification), and July to October (during stratification and turnover). The Mann-Whitney ***U*** test (Reckhow and Chapra 1984) was applied. Mann-Whitney ***U*** is a non-parametric test for assessing whether two samples of observations come from the same distribution. As shown in Figures 4.12, 4.13, 4.14, and 4.15, the populations of the seasonal data sets are distinctly different for total phosphorus, ortho-phosphate, total nitrogen, and total inorganic nitrogen.

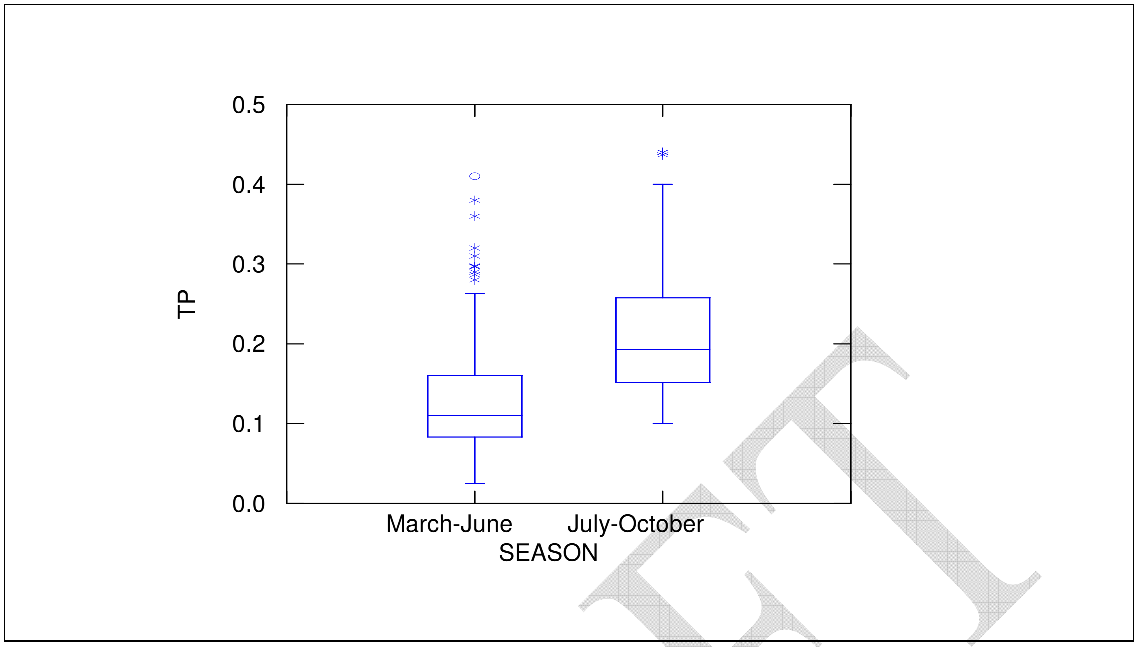

Figure 4.12: Box Plot presenting Seasonal Distribution (1990 to 2007) of Total Phosphorus (TP) Concentrations (mg/L) below Iron Gate Dam

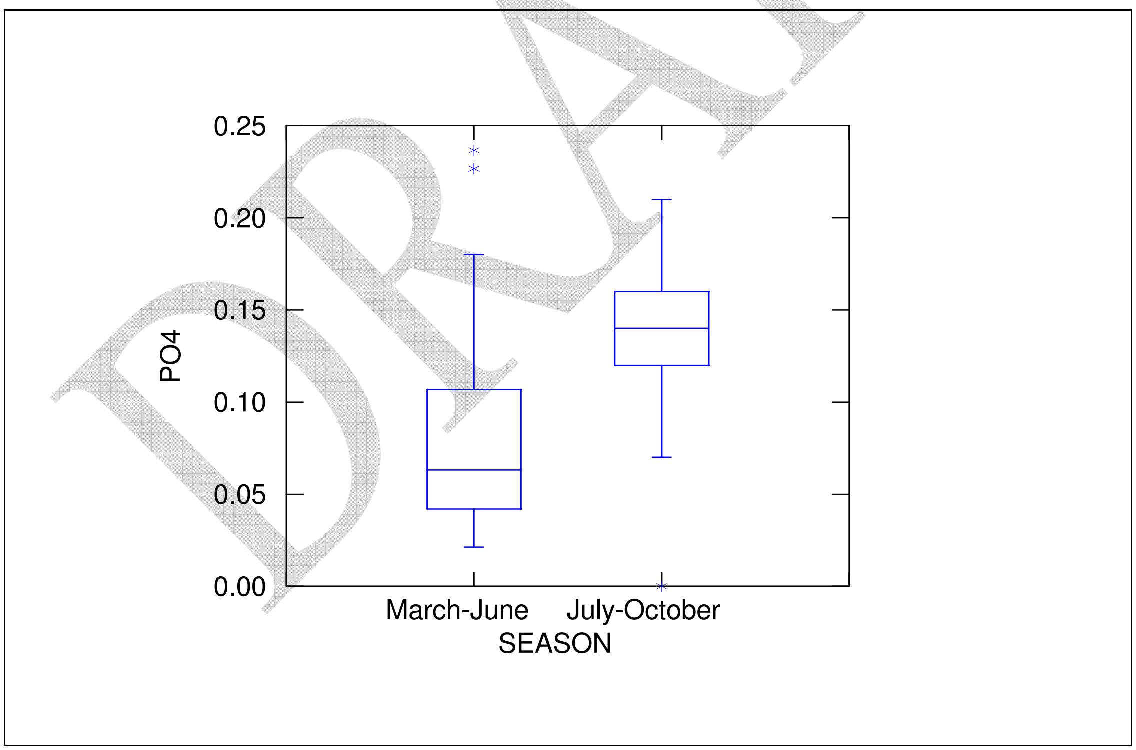

Figure 4.13: Box Plot presenting Seasonal Distribution of Ortho-Phosphate (PO4) Concentrations (mg/L) below Iron Gate Dam

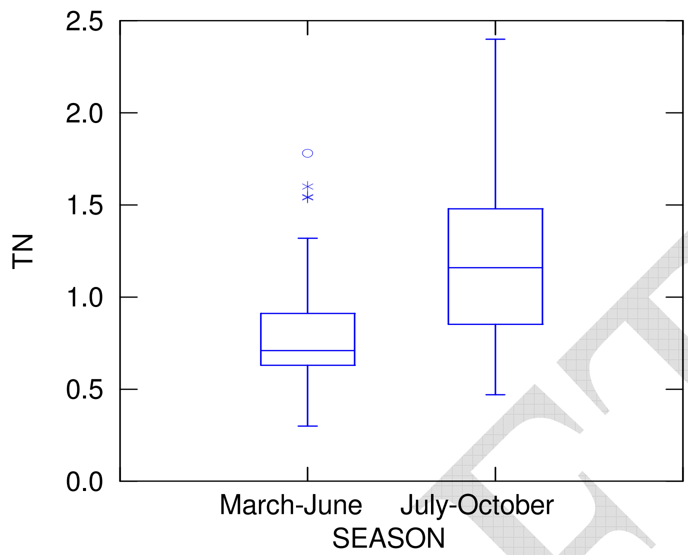

Figure 4.14: Box Plot presenting Seasonal Distribution of Total Nitrogen (TN) Concentrations (mg/L) below Iron Gate Dam

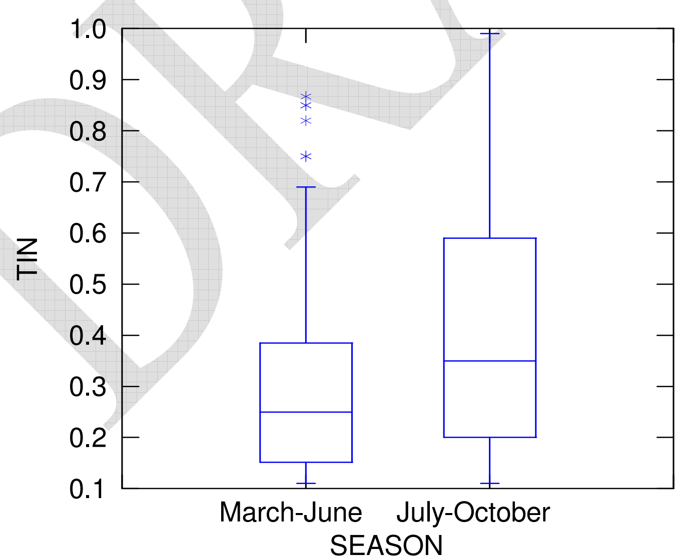

Figure 4.15: Box Plot presenting Seasonal Distribution of Total Inorganic Nitrogen (TIN) Concentrations (mg/L) below Iron Gate Dam

The higher concentrations of nutrients during the July to October period, compared with those during the March to June period, contribute to biostimulatory conditions of the river, and are due in part to the release of nutrients from the reservoir bottom sediments. This monitoring data appears to confirm the model predictions of reservoir benthic nutrient flux presented in Figure 4.11.

4.2.3 Iron Gate Hatchery

The California Department of Fish and Game operates a salmonid fish hatchery and rearing facility immediately downstream from Iron Gate Dam. Iron Gate Dam was constructed without volitional fish passage capabilities. Thus, the hatchery was completed concurrently with Iron Gate Dam in 1962 to mitigate for migrating salmonid stocks that would no longer have access to spawning and rearing habitat upstream from Iron Gate Dam. Since the hatchery is part of the mitigation required of PacifiCorp due to the blockage by the dam of salmonid habitat upstream of the dam, they are responsible for shared funding of hatchery operations.

Water for hatchery operations is supplied from Iron Gate Reservoir. There are two intakes from the reservoir which deliver water to the fish hatchery: one at a depth of approximately 18 feet and the other at a depth of approximately 74 feet below normal pool elevation (actual depths vary depending on the water level in the reservoir). During the cooler months water is withdrawn from 18 feet, though as water temperatures in the reservoir warm the intake point is moved to the lower depth (74 feet). Average flows through the hatchery system are 16.1 million gallons per day (mgd) (1494.6 cubic feet per second [cfs]), while maximum flows are 31.9 mgd (2961.4 cfs). The hatchery consists of a production pond system, where juvenile fish are reared, and two settling ponds. During daily operations, flows ranging from 7.75 to 15.5 mgd (719.5 to 1438.9 cfs) pass through the production and settling ponds and discharge directly into the Klamath River. These flows carry waste generated during the feeding and care of the fish including suspended solids, settleable solids, and chemicals used in disease control. When the fish production ponds are cleaned flows ranging from 1.9 mgd to 5.5 mgd, comprised of metabolic wastes, unconsumed food, algae, silt, and detritus, is released to settling ponds, and then into the Klamath River.

Due to the relatively small discharge flows from Iron Gate Hatchery, and the minimal water quality data characterizing the quality of the discharge, the Klamath TMDL model does not represent hatchery inputs. Therefore, the analysis of loads from the hatchery are based solely on empirical data.

4.2.3.1 <u>Temperature</u>

The current monitoring and reporting program for Iron Gate Hatchery does not require temperature monitoring. Thus, no temperature data are available to evaluate the effects of the hatchery effluent on the Klamath River. Regardless, because the discharge of elevated temperature waste is not allowed per the interstate water quality objective for temperature, any effluent discharged to the river at a higher temperature than the river exceeds the objective.

4.2.3.2 Nutrients and Organic Matter

Regional Water Board staff conducted a study during September through November 2004 to evaluate the hatchery discharge. Water to support hatchery operations is taken from the Iron Gate Reservoir from the deeper water layer. This water is aerated during transport to the hatchery. Flow through the hatchery remains relatively constant at 7.5 million gallons per day. The hatchery discharges water at two locations: (1) the rearing pens and (2) the settling ponds. Nutrient concentrations measured from these two discharges were statistically compared.

The *Mann-Whitney U Test* was used to assess the difference between the two hatchery discharges[3]. The test found there was no significant difference between the two discharges for both total phosphorus concentrations ($p = 0.689$) and total nitrogen concentration ($p = 0.479$). Based on these results, the two discharges were combined and treated as a single discharge for the hatchery nutrient loading estimates.

There are two potential sources of loading associated with the hatchery operations. Nutrient loads may be added to the downstream Klamath River due to within-hatchery processes such as stock feeding. Nutrient loads may also be added to the downstream Klamath River due to the withdrawal of water from the deeper, nutrient-enriched water layer in Iron Gate Reservoir for hatchery operations.

To estimate the total nutrient loading for the hatchery, concentrations measured upstream of Iron Gate Reservoir were used as background to compare to the combined discharge concentrations for the rearing and settling pond discharges. Daily loads were determined for each date of the 2004 study. These daily loads were extrapolated to the next date that samples were collected. The total load for the study period (69 days) was determined and normalized to a daily load. Annual loads for total phosphorus and total nitrogen were calculated from these daily load estimates.

The annual load to the Klamath River due to hatchery operations was estimated to be 1360 lbs of total nitrogen and 365 lbs of total phosphorous. These results suggest that the hatchery is a relatively minor source of nutrients to the Klamath River. Organic matter loading was not estimated of hatchery operations since measurements of CBOD were not collected during the 2004 study.

[3] The *Mann-Whitney U test* is a non-parametric test for assessing whether two samples of observations come from the same distribution. The method is also known as the Wilcoxon Rank-Sum test. This statistical test is a nonparametric (i.e., distribution-free) inferential statistical method. Nonparametric methods are most appropriate approach for assessing water quality data which can have widely varying frequency distributions. The test null hypothesis is that the two samples are drawn from a single population. The test is similar to performing an ordinary parametric two-sample *t* test, but is based on ranking the data set.

4.2.4 Tributaries

4.2.4.1 Temperature

Regional Water Board staff evaluated whether the major Klamath River tributaries (Shasta, Scott, Salmon, and Trinity Rivers) are contributing to the temperature impairment of the Klamath River by analyzing the influence those tributaries have on the temperature of the Klamath River itself, as well as the potential for those tributaries to provide thermal refugia for salmonids and other cold water species. The approach to analyzing these issues required the estimation of natural tributary flows and temperatures.

Two Klamath River model scenarios (TCT1 and TCT2) were developed to evaluate the effects of the major Klamath River tributaries on the temperatures of the Klamath River, as described in Section 3.3.3.2. Additional analyses were conducted to further understand how water management in the Shasta and Scott basins affect Klamath River temperature conditions, also described in Section 3.3.3.2. No additional analysis was conducted to evaluate effects of Salmon River on the Klamath River because the Salmon River TMDL found that current temperatures at the mouth of the Salmon River are consistent with natural baseline conditions.

The natural baseline conditions scenario represents estimated natural flows and temperatures in the Shasta, Scott, and Trinity Rivers, as well as estimated natural temperatures in the Klamath River upstream of the major tributaries. A range of natural Scott River flows estimates were evaluated due to the uncertainty of the natural flow estimates included in the natural baseline conditions scenario. The development of these scenarios is described in Section 3.3.3.2.

The California compliance scenario represents conditions expected from full compliance with: 1) the Scott and Shasta TMDLs, 2) the Trinity Record of Decision (ROD), and 3) attainment of water quality standards in the Klamath River upstream (i.e. at stateline, Iron Gate, and Copco). The Shasta, Scott, and Trinity River natural temperature estimates used in this analysis are meant to depict the absence of all anthropogenic impacts, representing full natural flows and site potential riparian shade conditions. The development of these scenarios is described in Section 3.3.3.2.

Shasta River

The California compliance scenario (TCT2) results indicate that the Shasta River would have a negligible temperature effect on the Klamath River. Figure 4.16 presents the difference in maximum daily Klamath River temperatures downstream and upstream of the Shasta River for both the current condition and California compliance scenarios. Figure 4.16 shows that the Shasta River could have a slight warming effect on the Klamath River in the fall months under California compliant conditions, but there is only a small temperature difference between the two simulation results otherwise.

The results of the natural conditions baseline scenario modeling analysis indicate that given natural temperature and flow conditions in the Klamath and Shasta Rivers, the

Shasta River may cool the daily maximum temperature of the Klamath River by as much as 1.0 °C (1.8 °F) during the summer season, with an average reduction of 0.5 °C (0.9 °F) from June through September. Figure 4.17 presents the difference in maximum daily Klamath River temperatures downstream and upstream of the Shasta River for both current and natural conditions.

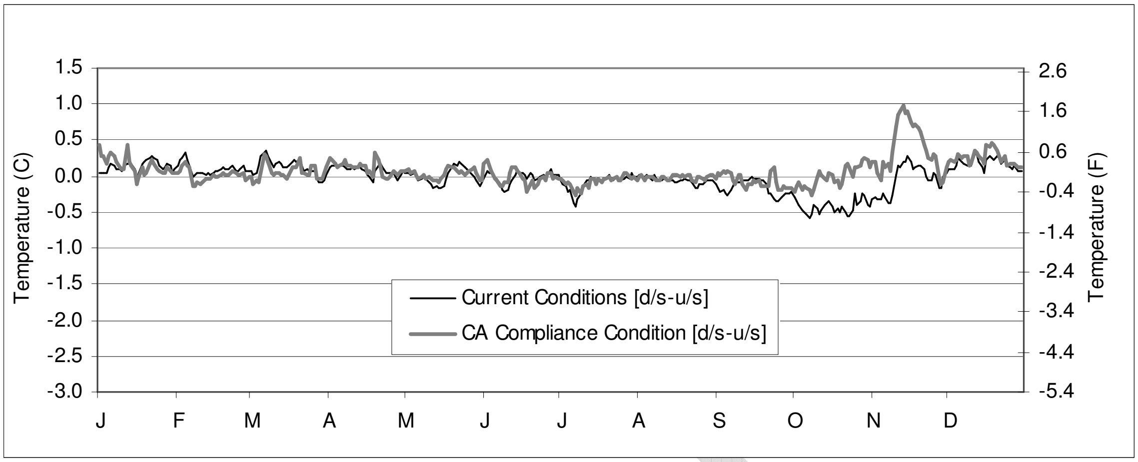

Figure 4.16: Change in Klamath River daily maximum temperatures resulting from current and Shasta TMDL compliant Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.

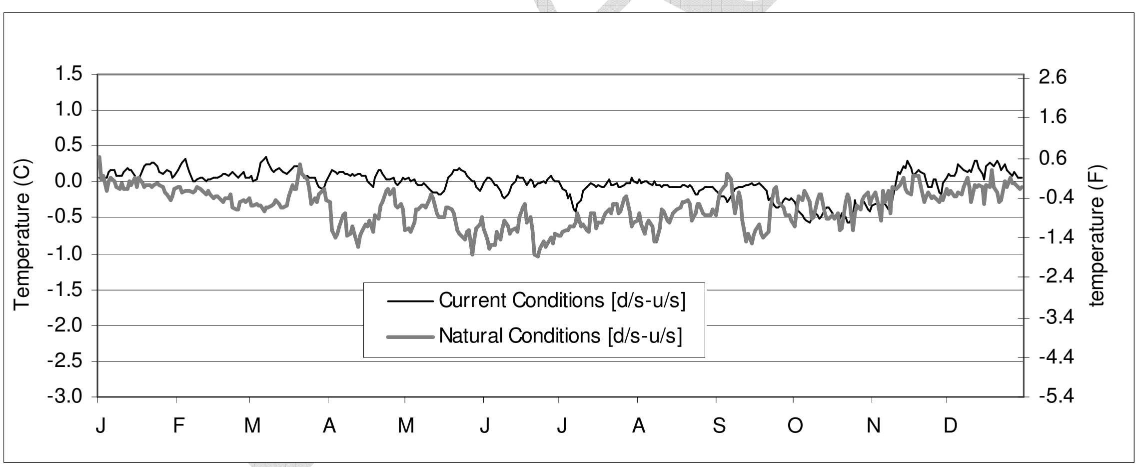

Figure 4.17: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.

Currently, Shasta River temperatures are too warm in the summer months to provide a thermal refuge for Klamath River salmonids. The California compliance scenario assumes a 1.6 °C (2.9 °F) daily average temperature reduction relative to current conditions at the mouth of the Shasta River, based on the Shasta TMDL temperature analysis (Regional Water Board 2006). The1.6 °C (2.9 °F) Shasta River temperature reduction depicted in the California compliance scenario improves conditions, but daily average temperatures are 20 ^oC (68 ^oF) or greater from mid-June to early September, as seen in Figure 4.18. The Shasta River temperature conditions depicted in the natural conditions baseline scenario, however, only exceed 20 ^oC (68 ^oF) for a few days during the year. Daily average temperatures greater than 20 ^oC (68 ^oF) are significant because temperatures above 20 ^oC (68 ^oF) have been shown to inhibit adult Chinook migration (see Appendix 3 [Carter 2008], Section 1.3.2). Thus, the results of this analysis indicate that the Shasta River would provide a thermal refuge for Klamath River salmonids under natural conditions, but would only provide a thermal refuge for a short time in the spring and fall under Shasta TMDL compliant conditions.

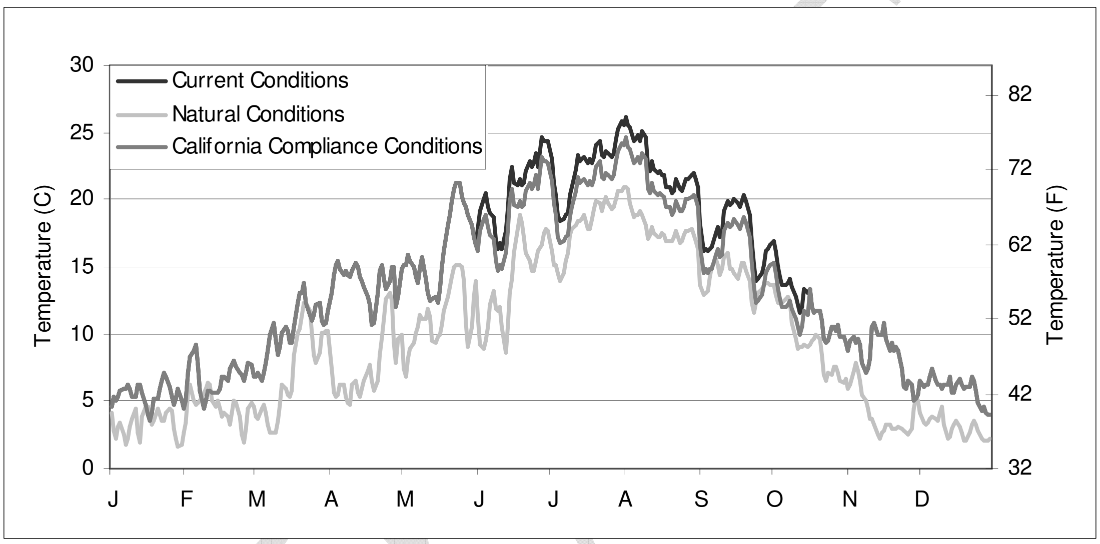

Figure 4.18: Estimated daily average Shasta River temperatures at the mouth of the Shasta River for the three management scenarios evaluated.

Scott River

The results of the California compliance condition scenario indicate that, given the conditions represented in the scenario, the Scott River would not change the Klamath River temperature much more than it currently does (Figure 4.19). An exception occurs during the height of the spring snow melt, in late May, when the Scott River cools the Klamath River an additional 1.0 ^oC (1.8 ^oF) in the California compliance scenario. Another exception occurs in the fall when the Scott River currently reduces the Klamath River temperature slightly, whereas it increases the Klamath River temperature slightly in the California compliance scenario. The difference is a result of the fact that in the California compliance scenario the Klamath River is much cooler during those months, compared to the current conditions scenario. The Scott River has nearly the same effect on the Klamath River in the two scenarios during the remainder of the season.

The results of the natural conditions baseline scenario indicate the Scott River could potentially have a significant temperature influence on the Klamath River, reducing temperatures by over 1.5 ^oC (2.7 ^oF) in June, and reducing temperatures by 0.5 - 1.0 ^oC (0.9 – 1.8 ^oF) during the remainder of the summer season (Figure 4.20). These results, however, reflect the most generous estimates of natural Scott River flows and temperatures. Given Regional Water Board staff concerns about the natural conditions baseline scenario estimates of Scott River Flows and temperatures, staff have developed more refined estimates of natural flow and temperatures, as described in Section 3.3.3.2. Staff evaluated how the Klamath River would be affected, given these refined Scott River natural flow and temperature estimates. The effect on Klamath River temperatures was assessed outside of the Klamath TMDL models, and were calculated using the mixing equation. The result of this additional analysis is presented in Figure 4.21. The results indicate that the Scott River would likely have a more negligible effect on Klamath River temperatures under these refined natural flow and temperature conditions than depicted in the natural conditions baseline scenario.

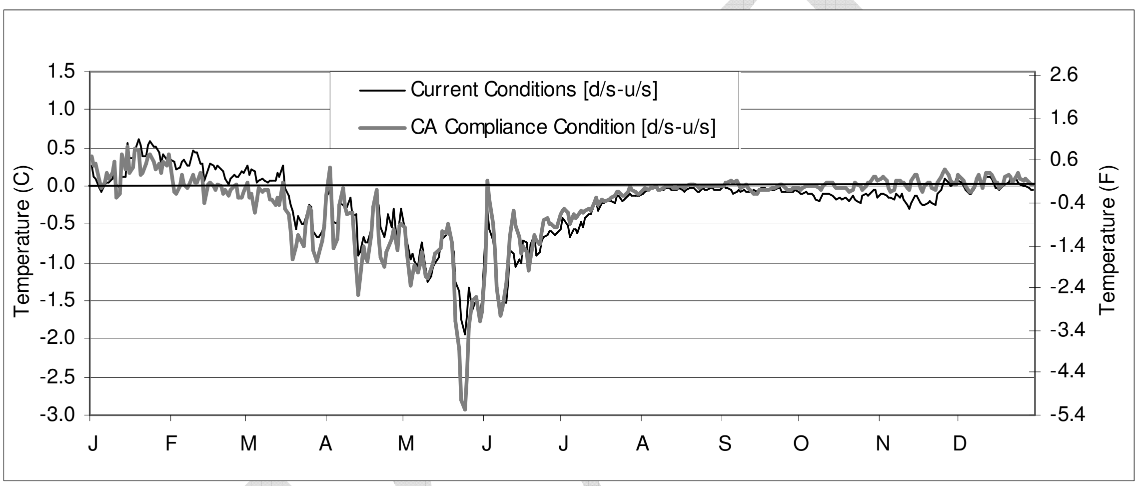

Figure 4.19: Change in Klamath River daily maximum temperatures resulting from current and Scott TMDL compliant Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.

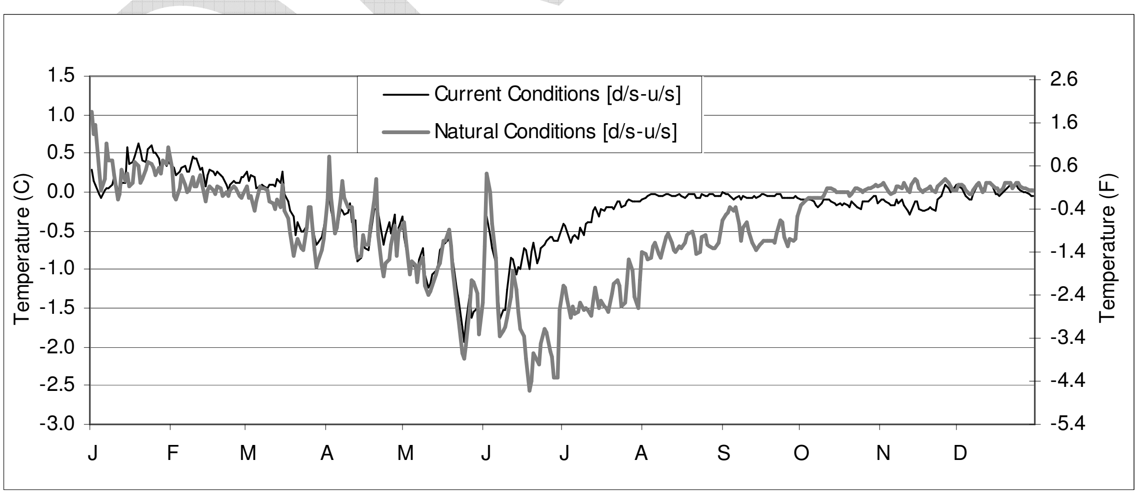

Figure 4.20: Change in Klamath River daily maximum temperatures resulting from current and originally estimated natural Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.

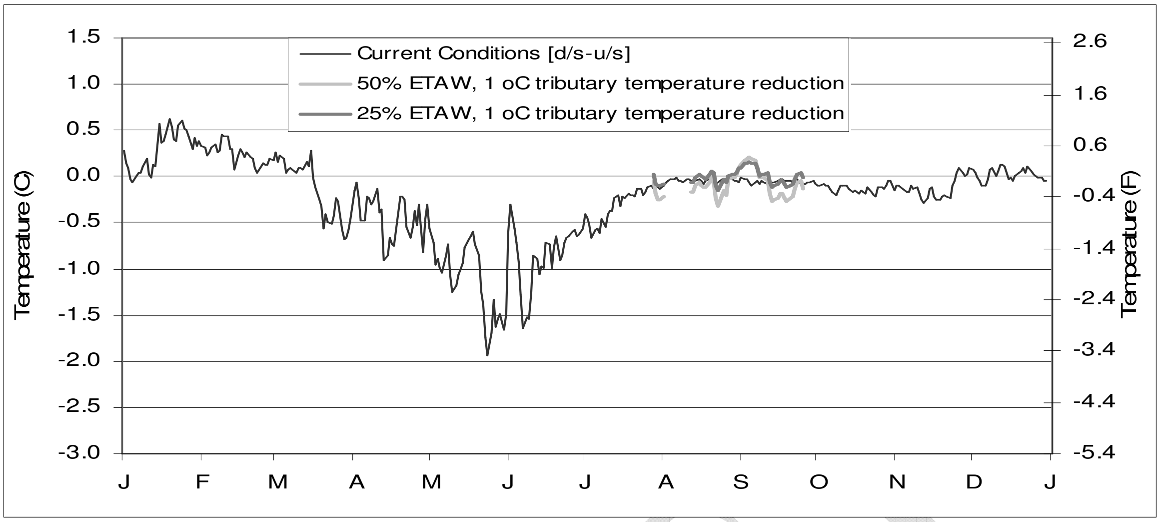

Figure 4.21 Change in Klamath River daily maximum temperatures resulting from current and revised natural Scott River conditions estimates. Negative values indicate that the Scott River is cooling the Klamath River.

Current Scott River temperatures are too hot to offer salmonids a thermal refuge from the high temperatures of the Klamath River. The results of the natural baseline conditions scenario indicate the Scott River would provide a marginal thermal refuge under those conditions (Figure 4.22). The additional analysis conducted by Regional Water Board staff indicates the conditions depicted in the natural baseline conditions are likely to overestimate natural flows and underestimate natural temperatures.

The natural flow estimate developed using the"50% ETAW" flow estimate and 1.0 ^{o}C (1.8 ^{o}F) reduction in tributary temperatures (50% ETAW) provides a more likely estimate of natural flow and temperature conditions. Figure 4.23 presents temperature estimates for two of the Scott River scenarios, as well as the temperatures compliant with California water quality standards in the Klamath River upstream of the Scott River. The results of the 50% ETAW estimate indicate the Scott would provide marginal thermal refuge during the late summer when adult salmonids are preparing for spawning.

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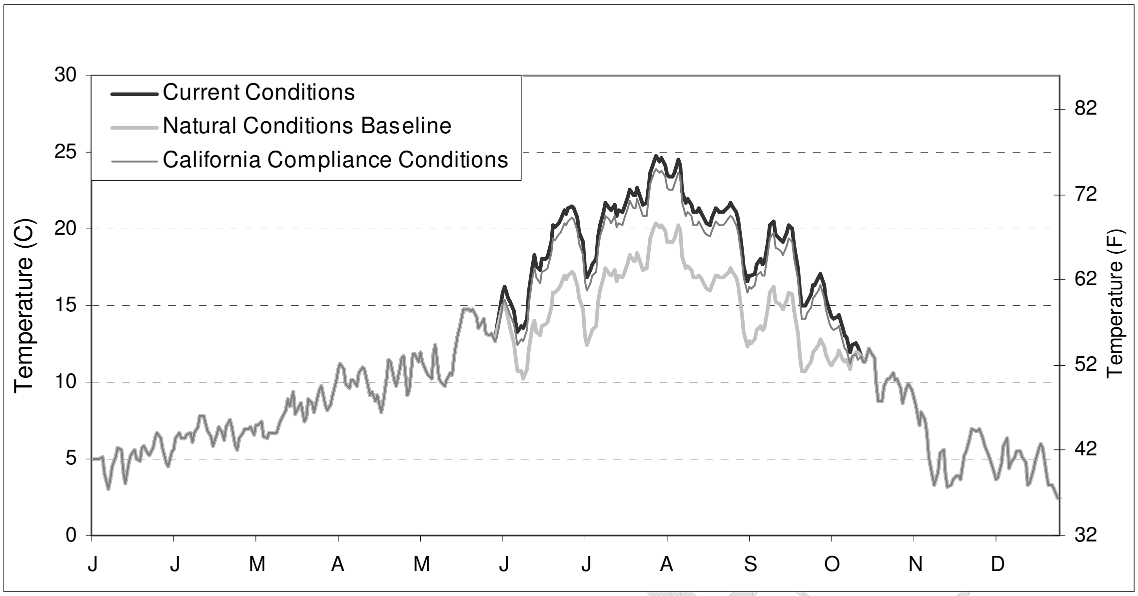


Figure 4.22: Estimated daily average Scott River temperatures at the mouth of the Scott River for three scenarios.

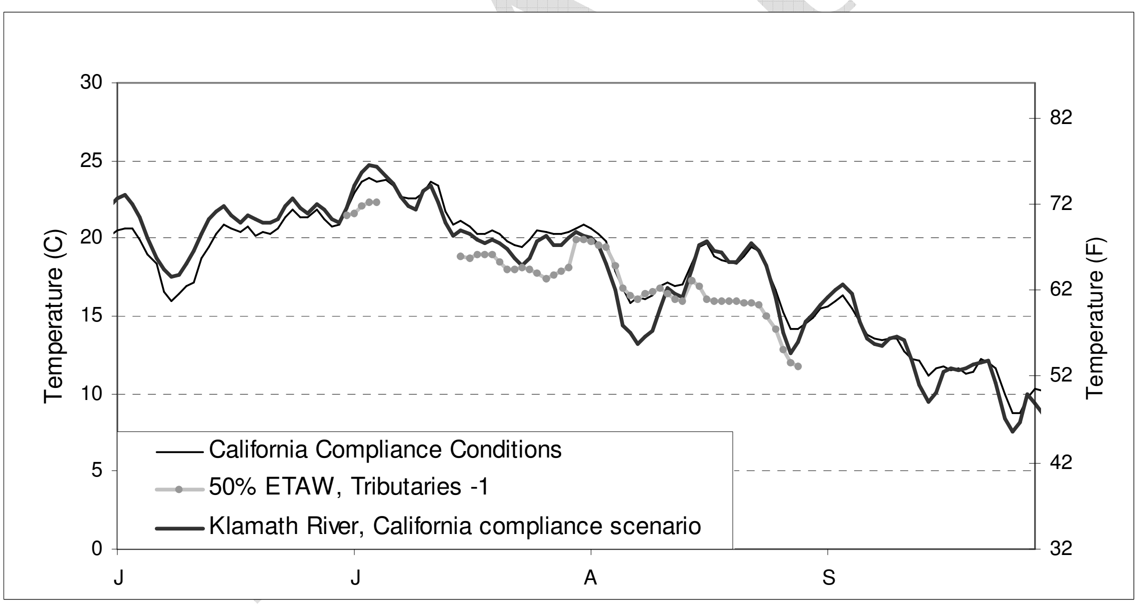


Figure 4.23: Comparison of estimated Scott River Temperature conditions to estimated Klamath River conditions.

<u>Trinity River</u>

The California compliance scenario modeling analysis indicates that natural Trinity River flows, as well as those prescribed by the ROD, have a moderate cooling effect on the Klamath River downstream of the Trinity River. Figure 4.24 presents the difference in daily maximum Klamath River temperatures downstream and upstream of the Trinity

River for both current and natural conditions. Similarly, Figure 4.25 presents the difference in daily maximum Klamath River temperatures downstream and upstream of the Trinity River for both current and Trinity ROD flow (i.e., California compliance scenario) conditions.

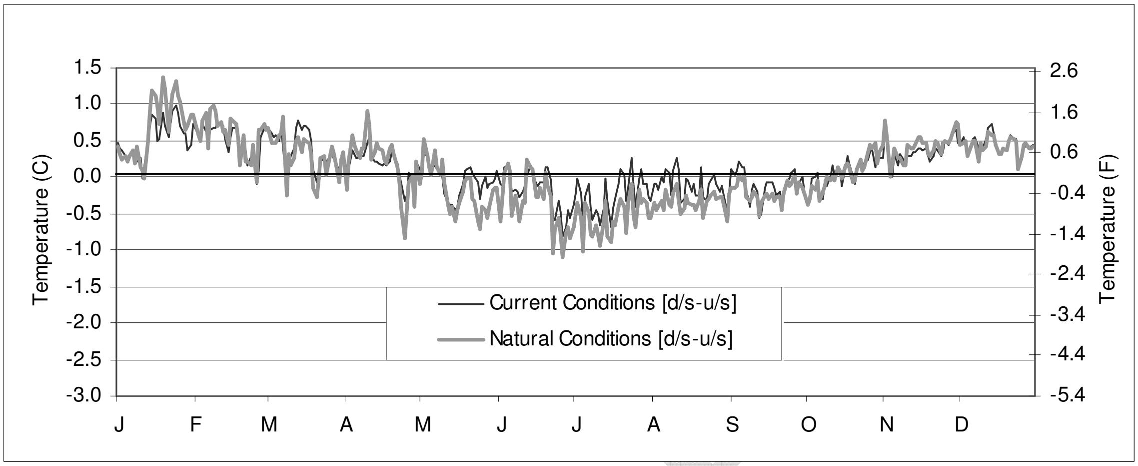


Figure 4.24: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Trinity River conditions. Negative values indicate that the Trinity is cooling the Klamath River.

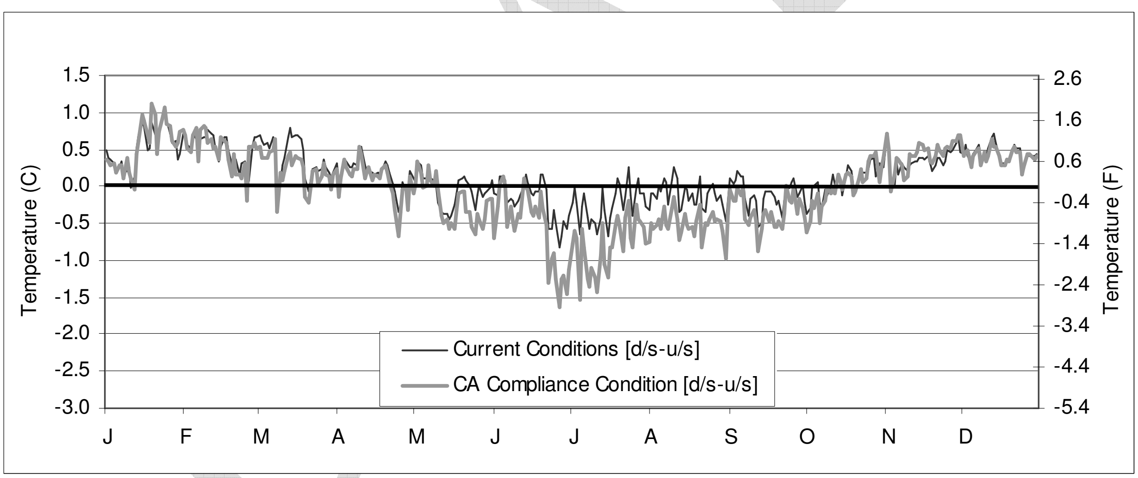


Figure 4.25 Change in Klamath River daily maximum temperatures resulting from current and Trinity ROD compliant Trinity River conditions. Negative values indicate that the Trinity River is cooling the Klamath River.

It is important to note that the upstream temperatures in the natural conditions baseline and California compliance scenarios reflect the absence of upstream reservoirs, as well as the effects of the estimated natural Shasta and Scott River inputs. These results are most apparent when comparing the difference between the estimated natural and Trinity ROD flow (i.e. California compliance) conditions. As discussed in Section 3.3.3.2, the estimated natural Trinity River flows and the Trinity ROD flows are equal during the summer months. However, the Trinity ROD flow scenario has a bigger effect downstream because the Klamath River temperatures upstream are warmer in comparison to the natural conditions scenario.

Effects of Shade on Klamath River Tributaries

Temperature TMDLs have been established for twelve watersheds in the north coast region of California. These watersheds include three of the major Klamath River tributaries: the Salmon, Scott, and Shasta River watersheds. All twelve temperature TMDLs have evaluated the effects of shade on stream temperatures and each of these analyses have consistently reached the same conclusion regarding stream shade: the temperature of a stream is significantly influenced by the amount of solar radiation the stream receives. A second conclusion of these analyses is that changes in streamside vegetation affect shade (and thus, temperature) to a greater degree in smaller streams than in large streams. This is largely due to the fact that the height of trees is greater in relation to stream width in smaller streams, whereas trees are less effective at casting shade on larger streams. These conclusions are consistent with published literature and temperature analyses conducted in the Pacific northwest (Independent Multidisciplinary Science Team, 2000; Johnson, 2004; Miner and Godwin, 2003; ODEQ, 2002).

Regional Water Board staff evaluated the sensitivity of Klamath River tributaries to the effects of solar radiation using the USGS stream reach temperature model SSTEMP. That analysis of six moderate-sized tributaries (Indian, Elk, Clear, Dillon, Red Cap, and Bluff Creeks) confirms the importance that solar radiation loads have in determining stream temperatures.

Given the similarity of Klamath River tributaries to other north coast watersheds, and the universal nature of the laws of thermodynamics, Regional Water Board staff have determined that the conclusions of shade-related analyses from previous temperature TMDLs stated above apply region-wide, and especially to Klamath tributaries not already assigned TMDL shade allocations. Riparian shade controls are needed in many Klamath River tributaries not subject to an existing TMDL Action Plan.

Effects of Sediment Loads on Klamath River Tributaries

Historic increases in sediment loads have resulted in the widening of stream channels, reduction of riparian shade, and consequent elevation of stream temperatures. The primary causes of increased sediment loads are both natural and human-caused mass wasting. The US Forest Service has estimated that 446 of the 2260 (20%) total stream miles evaluated within Klamath National Forest lands were significantly altered during the flood of 1997 (De la Fuente and Elder, 1998). Much of the damage done to stream channels happened when debris slides that had initiated in the headwater areas resulted in debris torrents that traveled long distances up to many miles, and in the process severely disrupted stream channels and removed riparian vegetation. Temperature data from one of the affected streams, Elk Creek, showed that in the summer after the flood, the peak temperature was the highest of seven years of record, and was 2.1 ^{o}C (3.8 ^{o}F) higher than the average from 1990-1995. Likewise, the diurnal variation increased to 6.9 ^{o}C (12.5^{o}F), 2.7 ^{o}C (4.9 ^{o}F) higher than the 1990-1995 average.

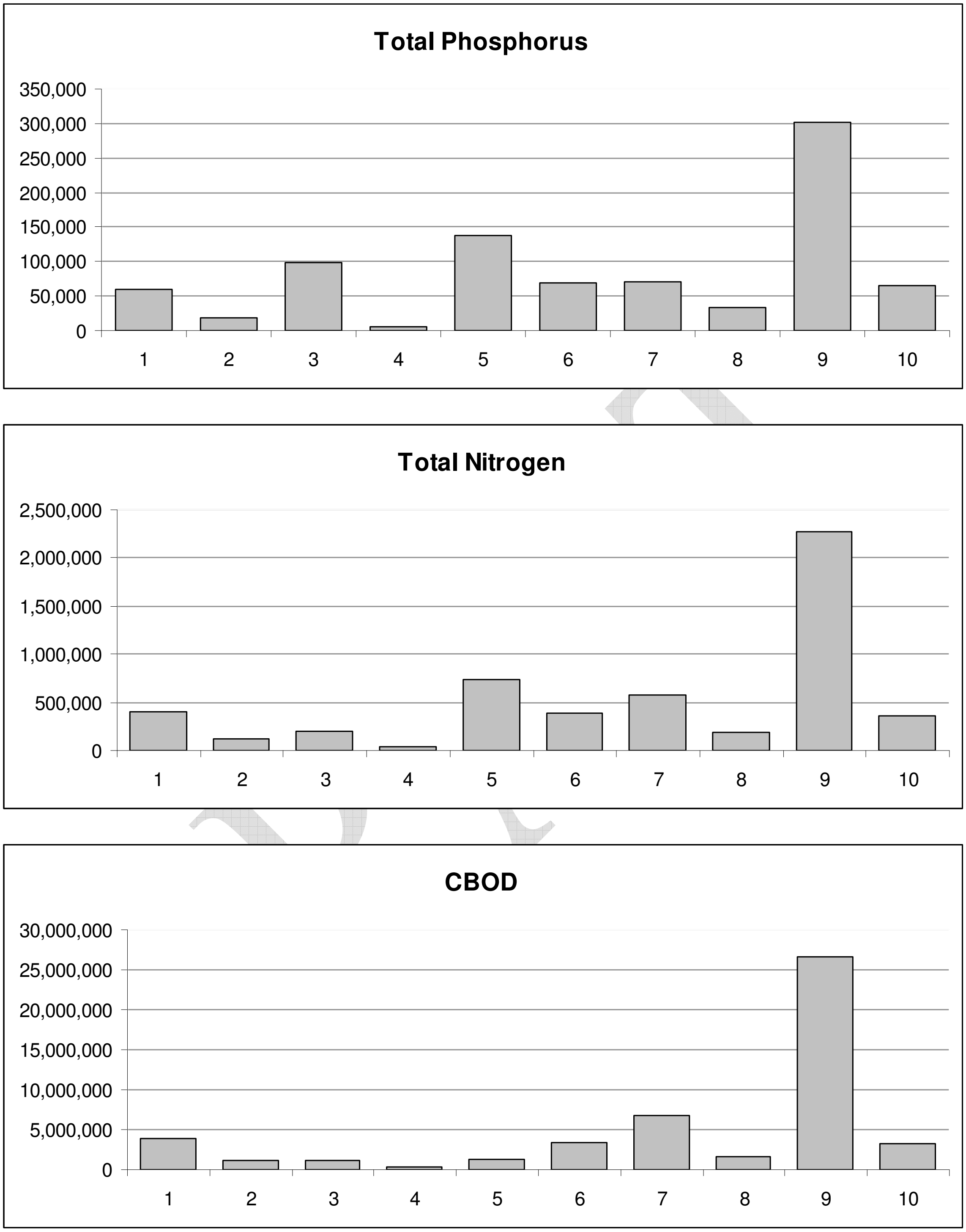
Regional Water Board staff evaluated the sensitivity of Klamath River tributaries to the effects of channel widening, using the USGS stream reach temperature model SSTEMP. The results of that analysis show that daily average stream temperatures can increase in the range of 1 ^{o}C to 2 ^{o}C when the wetted channel width doubles. However, these results are conservative given that the analysis only evaluated the effects of a change in wetted width and did not consider the loss of riparian vegetation (and consequent decrease in shade) that occurs when the active channel increases in width following a debris torrent or aggradation event. Furthermore, because the downstream endpoints of the modeled reaches are near the mouths of the streams where streams are already near equilibrium, it is likely that even larger temperature increases would occur in some reaches upstream where the difference between the current temperature and the equilibrium temperature is greater. Regional Water Board staff have also identified an apparent correlation of decreases in temperature with decreases in channel width in thermal infrared survey data (Watershed Sciences, LLC 2004).

Increased sediment loads in tributary streams also create temperature impacts associated with loss of thermal refugia in the Klamath mainstem. Because the daily maximum temperatures of the Klamath mainstem are at lethal levels through most of the summer, the opportunity for salmonids to rear in the mainstem during those times depends on access to thermal refugia. The majority of thermal refugia in the Klamath mainstem are located at the mouths of cold tributaries where they mix with the Klamath River (Belchik 1997). The volume of thermal refugia at tributary mouths can be greatly affected by the sediment loads of the tributaries. Higher sediment loads can cause tributaries to infiltrate into gravels before reaching the river, create barriers that restrict fish from entering tributaries, and fill in pools where cold water exists. Three of the four largest (>1000 ft^2) thermal refugia areas are created by tributaries that were significantly impacted by sediment loads during the 1997 flood event.

4.2.4.2 <u>Nutrients and Organic Matter</u>

Current annual nutrient and CBOD loads from the California tributaries to the Klamath River are presented in Figure 4.26. Loads are presented for the Shasta, Scott, Salmon, and Trinity Rivers, and for groups of tributaries located between each of the major tributaries. These loads were calculated based on the best available quality assured concentration data from 2000 through 2007 and flows from the 2000 calendar year. Cumulatively the California tributaries account for 48.4%, 48%, and 71%, respectively, of the current annual TP, TN, and CBOD loads to the Klamath River in California.

The Shasta River TMDL, which addresses temperature and DO impairments, requires reductions in nutrient and organic matter loads within the Shasta River watershed. For the Klamath River TMDL source analysis, the nutrient and CBOD loads from the Shasta River were calculated based on Shasta River TMDL compliant conditions. These TMDL compliant Shasta River loads reflect the expected annual loads to the Klamath River when the Shasta River TMDL is fully implemented and nutrient/ biostimulatory substances and DO water quality objectives within the Shasta River are achieved. For the



Stations List:

1- Stateline to Iron Gate Tributaries
2- Iron Gate to Shasta Tributaries
3- Shasta River
4- Shasta to Scott Tributaries
5- Scott River
6- Scott to Salmon Tributaries
7- Salmon River
8- Salmon to Trinity Tributaries
9- Trinity River
10- Trinity River to Turwar Tributaries

Figure 4.26: Current Total Annual Loading (Pounds/Year) of Total Phosphorus, Total Nitrogen, and CBOD to the Klamath River from California Tributaries

Klamath River TMDL source analysis, these Shasta River TMDL compliant nutrient and CBOD loads are considered to represent natural conditions baseline. Figure 4.27 compares current and natural conditions baseline TP, TN, and CBOD loads from the Shasta River. The Shasta TMDL compliant conditions represent 72%, 59%, and 18% reductions, respectively, from current TP, TN, and CBOD loads.

For purposes of the Klamath River TMDL source analysis, the current nutrient and CBOD loads from the other California tributaries are considered to be consistent with natural conditions baseline. The nonpoint source control measures identified in the implementation plan will, however, apply to these tributaries.

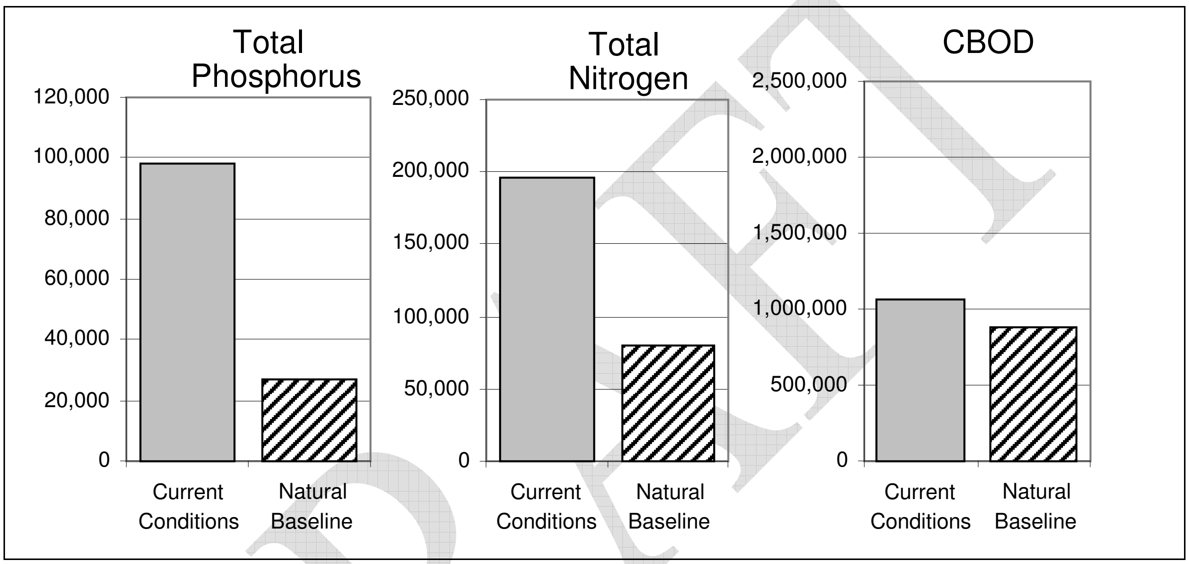


Figure 4.27: Shasta River Comparison of Current Loads (pounds/year) of TP, TN, and CBOD with Natural Conditions Baseline Loads.

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